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Weld Strength Verification and Proposed Weld Testing and Inspection Criteria for the MK83 and MK84 Conical Bomb Fins

by Marc S. Pepi and Victor K. Champagne

ARL-TR-2862 October 2002

performed for

The Naval Air Warfare Center
Pt. Mugu, CA 93042

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Abstract

The U.S. Army Research Laboratory (ARL) performed weld strength verification testing on manufactured specimens to characterize four different types of welds found on both the MK83 and MK84 conical bomb fins. Based on the results obtained by testing, as well as existing requirements, ARL established test and inspection criteria that may be employed at the discretion of the Naval Air Warfare Center for future First Article Inspections and/or during production as a tool for evaluating the quality and integrity of the weldments.

Acknowledgments

The authors wish to thank Robert Fusick of Aerotek Welding, North Granby, CT, for his input in determining the welding parameters and for the fabrication of the welding specimens.

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1. Background

The U.S. Army Research Laboratory's (ARL's), Weapons and Materials Research Directorate (WMRD) was requested to establish test and inspection criteria for selected welds of the MK83 and MK84 conical bomb fins by the Naval Air Warfare Center (NAWC), Pt. Mugu, CA. This was necessitated when a manufacturer of these bomb fins expressed concern during a First Article Inspection (FAI) that the spot weld mechanical property listed on the governing engineering drawing was slightly excessive. The contractor felt that even perfect welds may not be able to meet this requirement due to dimensional tolerancing allowances and property variation within the steel sheet. The bomb fins are currently fabricated according to specifications outlined within the Naval Air Systems Command (NAVAIRSYSCOM) drawings 1380505 and 1380529 [1], respectively. Their purpose is to stabilize gravity bombs after deployment in order to provide accurate targeting. To establish the mechanical property requirements for these welds, test specimens representing the different types of welds used to fabricate the bomb fins were produced by Aerotek Welding Co., Inc., North Granby, CT. This investigation focused on the plug, spot, and seam (resistance) and the fillet (fusion) welds. With respect to the bomb fins under investigation, the plug weld joins the skin segment to the conical fin spar assembly, the spot weld fastens the spars together to form the spar assembly, and the seam weld joins the steel sheet of the conical fin skin. The fillet weld fastens the conical fin skin to the ring adapter. Mechanical testing and metallographic examination were performed by ARL to evaluate the integrity of each type of weld. Strength requirements as well as inspection criteria were established for each of these welds and are presented to the NAWC for possible inclusion in the appropriate automated data lists (ADLs) or drawing packages to be used at their discretion during FAIs and/or production.

2. Drawing/Specification Review

Table 1 summarizes the applicable NAVAIRSYSCOM drawings [1] and subtier specifications for each of the welds and bomb fins under investigation.

Table 1. Weld drawings and specifications.

Weld	NAVAIRSYSCOM Drawing (MK83 conical fin)	NAVAIRSYSCOM Drawing (MK84 conical fin)	Applicable Welding Specification
Plug	1380509, Rev. P	1380534, Rev. U	MIL-W-8611,[a] (S/S by MIL-STD-2219,[b] Class B)
Spot	1350494, Rev. K	1380537, Rev. K	MIL-W-12332[c]
Seam	1380507, Rev. M	1380533, Rev. R	MIL-W-12332, alt.: MIL-STD-2219, Class B
Fillet	1380506, Rev. M	1380531, Rev. U	MIL-W-8611, (S/S by MIL-STD-2219, Class A)

a See reference [2].

b See reference [3].

c See reference [4].

3. Current Visual/Nondestructive/Mechanical Property and Metallographic Requirements

The applicable engineering drawings and specifications were reviewed in order to determine the current bomb fin weld requirements for visual examination, nondestructive inspection (NDI), mechanical properties, and metallographic examination. Table 2 lists the current requirements for visual examination, while Table 3 lists those for NDI. Tables 4–6 list the current requirements for mechanical properties and metallographic examination, respectively.

Table 2. Required visual inspection criteria for each weld.

Weld	Specification	Required Visual Inspection
Plug	MIL-STD-2219, Class B	5.4.4.1: "…Arc strikes, arc burns from loose electrical connections and gouge marks on the base metal of the finished weldment are unacceptable for Class A and B welds." Surface requirements for porosity, undercut, and underfill and/or concavity are outlined in Table 5-4 of MIL-STD-2219.
Spot	MIL-W-12332	7.3.1: "The outer surface of all welds shall be smooth and free or cracks, tip pickup, pits, metal expulsion, and other defects which indicate that the welds were made with contaminated electrodes or with improperly prepared surfaces."
Seam	MIL-W-12332, alt.: MIL-STD-2219, Class B	7.3.1: "The outer surface of all welds shall be smooth and free or cracks, tip pickup, pits, metal expulsion, and other defects which indicate that the welds were made with contaminated electrodes or with improperly prepared surfaces."
Fillet	MIL-STD-2219, Class A	5.4.4.1: "…Arc strikes, arc burns from loose electrical connections and gouge marks on the base metal of the finished weldment are unacceptable for Class A and B welds." Surface requirements for porosity, undercut, and underfill and/or concavity are outlined in Table 5-4 of MIL-STD-2219.

Table 3. Required NDI methods for each weld.

Weld	Required Nondestructive Inspection
Plug	Magnetic Particle Inspection (MPI) (ASTM E1444[a] or liquid penetrant ASTM E1417[b])
Spot	None
Seam	None
Fillet	MPI (ASTM E1444 or liquid penetrant ASTM E1417) and radiography (ASTM E1742[c])

[a] See reference [5].
[b] See reference [6].
[c] See reference [7].

Table 4. Current weld mechanical property requirements – MK83 bomb fin.

Weld	Governing Drawing	Subtier Specification	Mechanical Property Requirement
Plug	1380509, Rev. P	MIL-STD-2219, Class B	None listed (drawing or specification)
Spot	1350494, Rev. K	MIL-W-12332	3200 lb/inch (drawing), MIL-W-12332: Peel test (failure outside weld area is acceptable, with a minimum required button diameter of 0.29 inch, measured in two perpendicular directions).
Seam	1380507, Rev. M	MIL-W-12332, alt.: MIL-STD-2219, Class B	2600 lb/inch (drawing)
Fillet	1380506, Rev. M	MIL-STD-2219, Class A	None listed (drawing or specification)

Table 5. Current weld mechanical property requirements – MK84 bomb fin.

Weld	Governing Drawing	Subtier Specification	Mechanical Property Requirement
Plug	1380534, Rev. T	MIL-STD-2219, Class B	None listed (drawing or specification)
Spot	1380537, Rev. J	MIL-W-12332	MIL-W-12332: Peel test (failure outside weld area is acceptable, with a minimum required button diameter of 0.29 inch, measured in two perpendicular directions).
Seam	1380533, Rev. P	MIL-W-12332, alt.: MIL-STD-2219, Class B	2600 lb/inch (drawing)
Fillet	1380531, Rev. T	MIL-STD-2219, Class A	None listed (drawing or specification)

Table 6. Required metallographic examination criteria for each weld (both fins).

Weld	Specification	Required Metallographic Examination
Plug	MIL-STD-2219, Class B	None
Spot	MIL-W-12332	7.3.3.3.1: "The weldment or simulated specimen shall be cross-sectioned and etched. The nugget penetration shall be 30 percent to 80 percent of the sheet thicknesses involved..."
Seam	MIL-W-12332, alt.: MIL-STD-2219, Class B	7.3.3.3.1: "The weldment or simulated specimen shall be cross-sectioned and etched. The nugget penetration shall be 30 percent to 80 percent of the sheet thicknesses involved. The width of the seam weld shall conform to Table III." (0.22-inch for 0.078-inch-thick steel)
Fillet	MIL-STD-2219, Class A	None

4. Test Specimen Fabrication

Aerotek fabricated test specimens according to the requirements of the governing engineering drawings and applicable specifications. One may argue that these welds were generated under "laboratory" and almost optimal conditions, with none of the constraints imposed by not only the conical geometry of the part but by a production setting. However, it was felt that if proper workmanship and quality controls were adhered to, the specimens produced in this study could also be achieved on actual bomb fins during production. The parameters utilized by Aerotek are listed in Appendix A (plug welds), Appendix B (spot welds), Appendix C (seam welds), and Appendix D (fillet welds). As highlighted in Appendices A and D, the plug and fillet welds were produced in accordance with MIL-W-8611. This specification was later superceded by MIL-STD-2219. The spot and seam welds were produced in accordance with MIL-W-12332. The chemical analysis of the weld wire is listed in Appendix E. All welding was performed on 0.075 ± 0.007-inch-thick AISI 1010 steel sheet and bar stock (hot-rolled drawing quality). A representative specimen from each group is shown in the as-received condition in Figures 1–4.

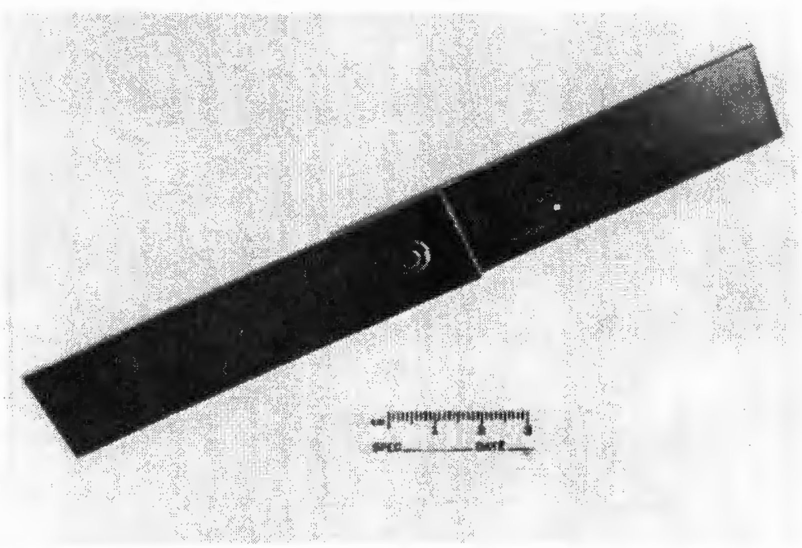

Figure 1. Representative plug weld specimen in the as-received condition; reduced 25%.

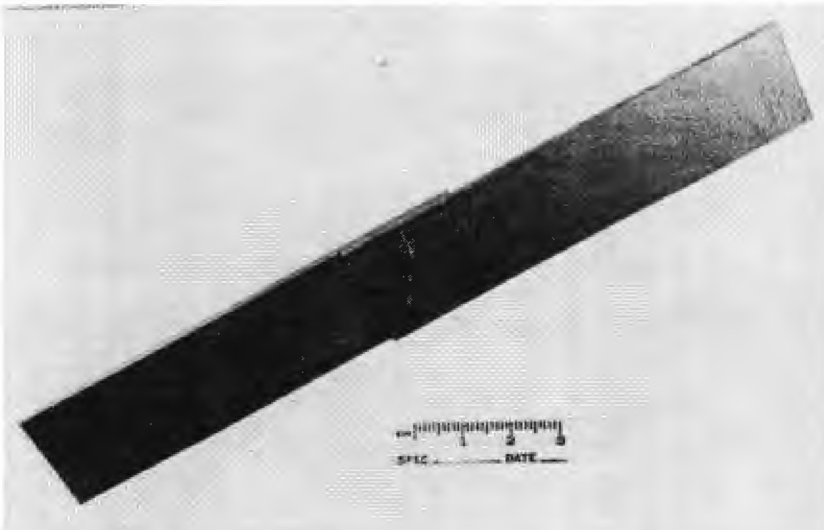

Figure 2. Representative spot weld specimen in the as-received condition; reduced 25%.

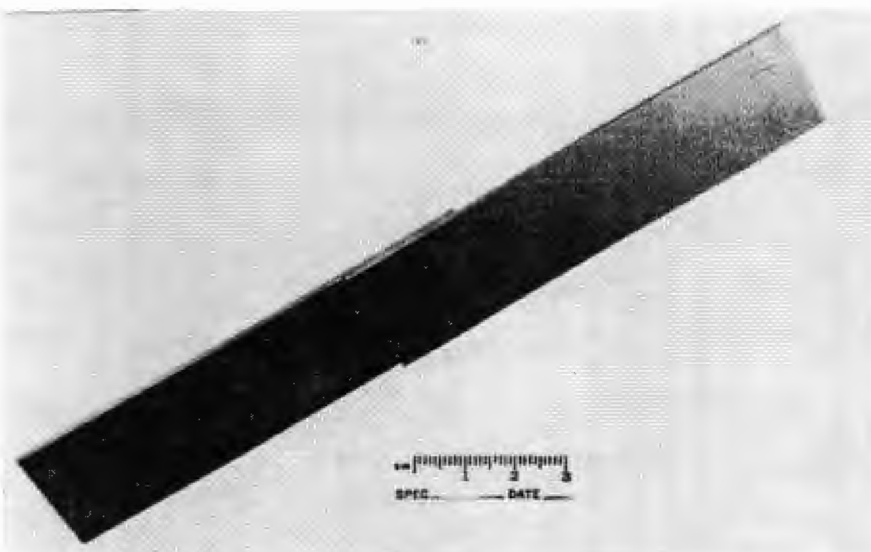

Figure 3. Representative seam weld specimen in the as-received condition; reduced 25%.

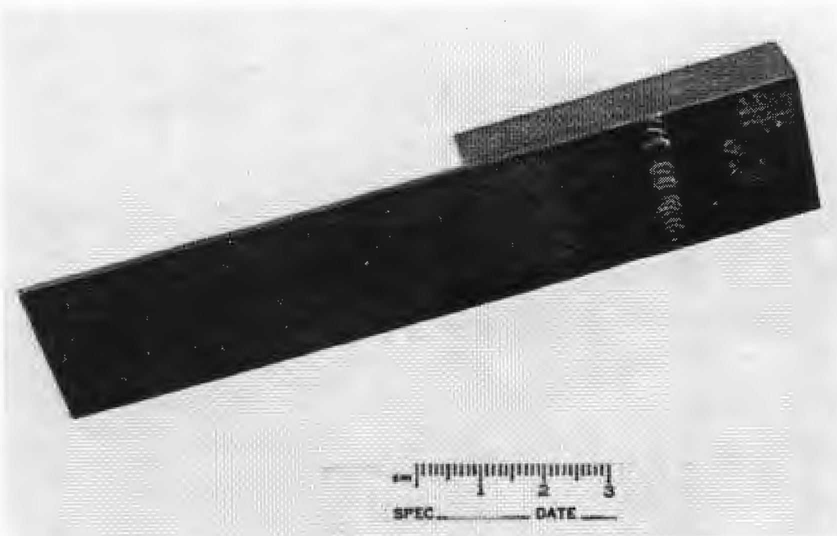

Figure 4. Representative fillet weld specimen in the as-received condition; reduced 25%.

4.1 Plug Weld Specimens

Twenty-four plug weld specimens were fabricated from two 4- × 24-inch AISI 1010 steel sheets, in conformance with MIL-W-8611. The two steel sheets overlapped by 1 inch in the center, as shown in Figure 5. The steel sheets were prepared using 120-grit silicon carbide paper, and the weld region was cleaned with acetone prior to welding. The parts were scribed prior to welding to ensure proper overlap. Holes 0.25 inch in diameter were drilled into one of the steel sheets to be filled by the plug welds. The two pieces were clamped to bar stock to avoid excessive penetration. Each side of the plug weld was clamped during the welding operation.

The sheets were welded moving the clamps to the area being welded, letting the piece cool in the clamped state. Figures 6 and 7 illustrate the two-piece steel assembly as welded prior to specimen sectioning at the Aerotek plant. The plug welds were distanced 1/2 inch from the edge of the steel sheets and spaced 1 inch from each other. The welded sheets were cut without burning into 1.000 +0.005/−0.000-inch wide tensile shear specimens, with the plug weld centered in each strip. This strict tolerance constraint ensured uniformity during testing. The strips were labeled 1 to 24 in order of construction to determine the presence of any time effects. The electrodes utilized were in conformance with MIL-E-23765/4 [8], Type 70S-2.

4.2 Spot Weld Specimens

Twenty-four spot weld specimens were fabricated from two 4- × 24-inch steel sheets, in conformance with MIL-W-12332. The spot welds had a 0.300-inch diameter. The two steel sheets overlapped by 1 inch in the center, as shown in Figure 8. The steel sheets were prepared using 120-grit silicon carbide paper, and the weld region was cleaned with acetone prior

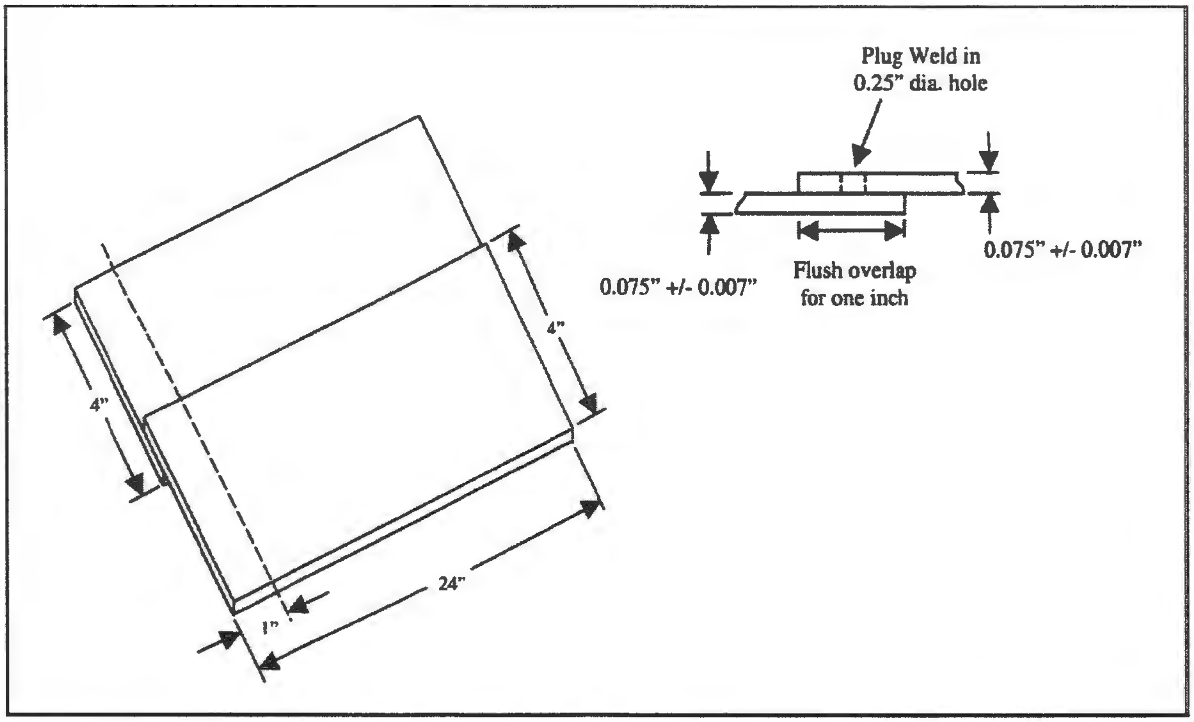

Figure 5. Schematic illustrating dimensions of plug weld assembly.

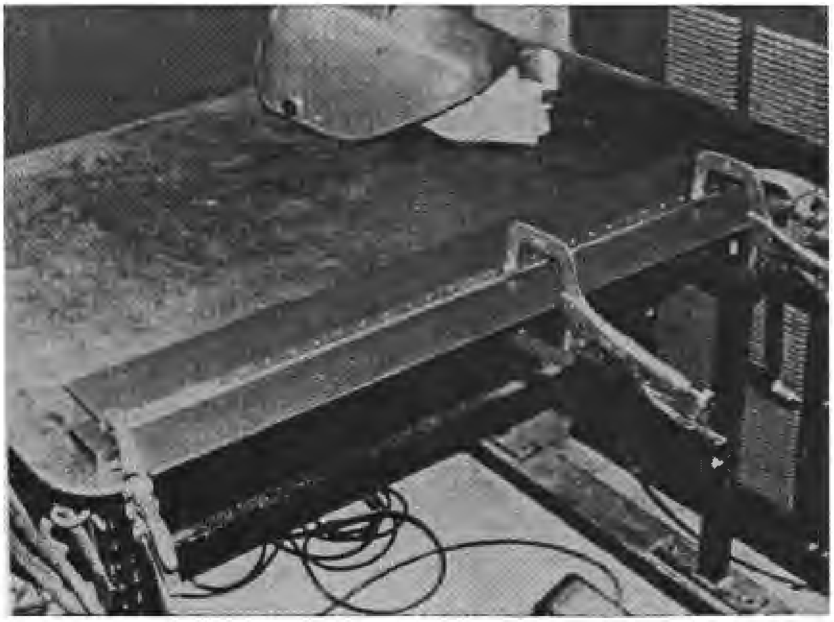

Figure 6. Photograph showing plug weld assembly at Aerotek Welding.

to welding to ensure proper overlap. The two pieces were clamped to bar stock to avoid excessive penetration. Each side of the spot weld was clamped during the welding operation. Similar to plug weld fabrication, the sheets were welded moving the clamps to the area being welded letting the piece cool in the clamped state. The spot welds were distanced 1/2 inch from the edge of the steel sheets and spaced 1 inch from each other.

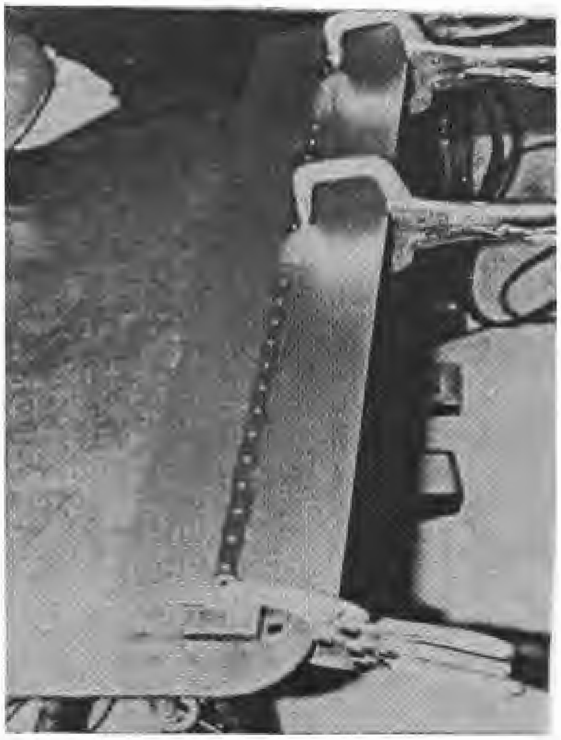

Figure 7. Photograph showing another view of the plug weld assembly at Aerotek Welding.

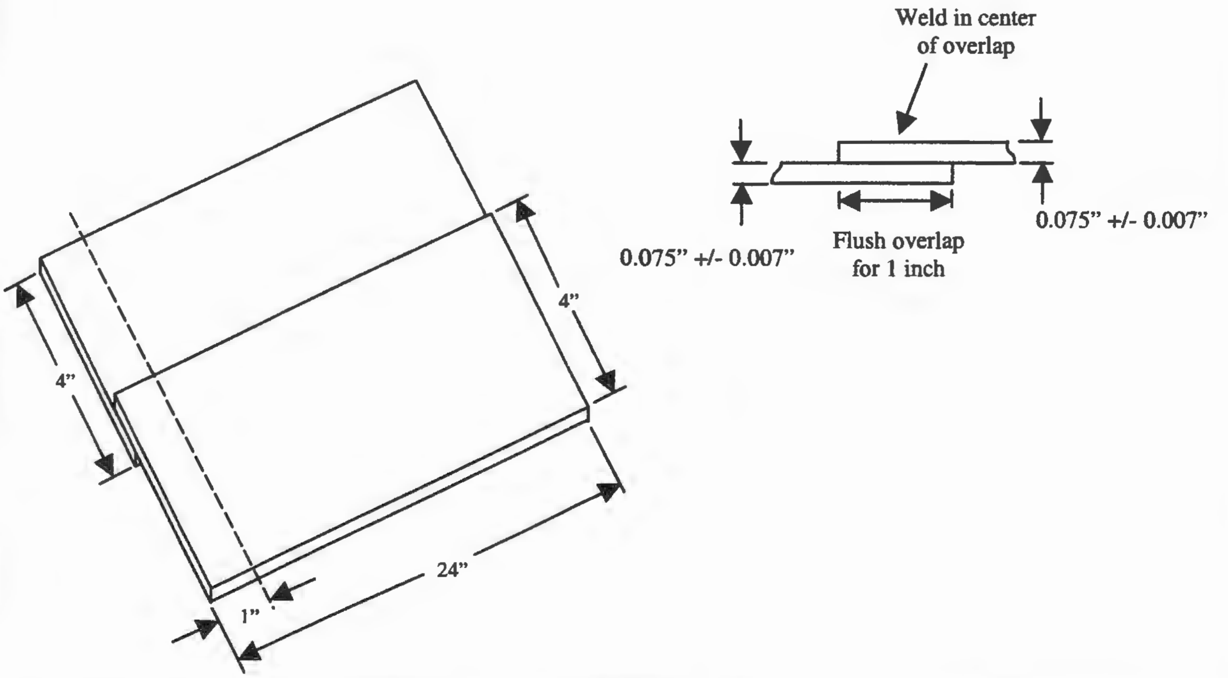

Figure 8. Schematic illustrating dimensions of spot weld assembly.

The welded sheets were cut without burning into 1.000 +0.005/−0.000 inch wide specimens, with the spot weld centered in each strip. The strips were labeled 1 to 24 in order of construction.

4.3 Seam Weld Specimens

Twenty-four seam weld tensile shear test specimens were fabricated from two 4- × 2-inch steel sheets, in conformance with MIL-W-12332. The two steel sheets overlapped by 1 inch in the center, as shown in Figure 8. The seam weld was centered in this overlap region. The steel sheets were sanded utilizing 120-grit silicon carbide paper, and the weld region was cleaned with acetone prior to welding. The parts were scribed prior to welding to ensure proper overlap. The parts were tack welded prior to being seam welded, at 6-inch intervals. The welded sheets were cut without burning into 1.000 +0.005/−0.000-inch wide specimens. The strips were labeled 1 to 24 in order of construction. The electrodes conformed to MIL-E-18193 [9], type and class optional.

4.4 Fillet Weld Specimens

Finally, 24 fillet weld tensile shear test specimens were fabricated from a two-piece AISI 1010 steel assembly, in conformance with MIL-W-8611, as shown in Figure 9. The steel pieces were sanded utilizing 120-grit silicon carbide paper, and the weld region was cleaned with acetone prior to welding. The parts were fit together and held down with a clamp bar (as illustrated in Figure 10). The parts were then tack welded at 4-inch intervals. The weld was subsequently performed, and the parts were left to cool in the clamped state. The fillet weld attached a 6- × 24-inch steel sheet to a 1/2-inch bar, simulating the fillet weld on the MK83 and MK84 conical bomb fins. Figures 11 and 12 illustrate the two-piece steel assembly as welded and prior to specimen cutting at the Aerotek plant. The welded sheets were cut without burning into 1.000 +0.005/−0.000-inch wide specimens. The strips were labeled 1 to 24 in order of construction. The electrodes utilized were in conformance with MIL-E-23765/4 [8], Type 70S-2. The specified maximum allowable height of the weld was 0.06 inch, and grinding was permissible to meet this requirement.

5. Visual Examination

The outer surface of all the weld specimens was smooth and free of cracks, tip pickup, pits, metal expulsion, and any other defects that would have indicated that the welds were made with contaminated electrodes, improperly prepared surfaces, or with poor workmanship. NDI was not performed on these specimens.

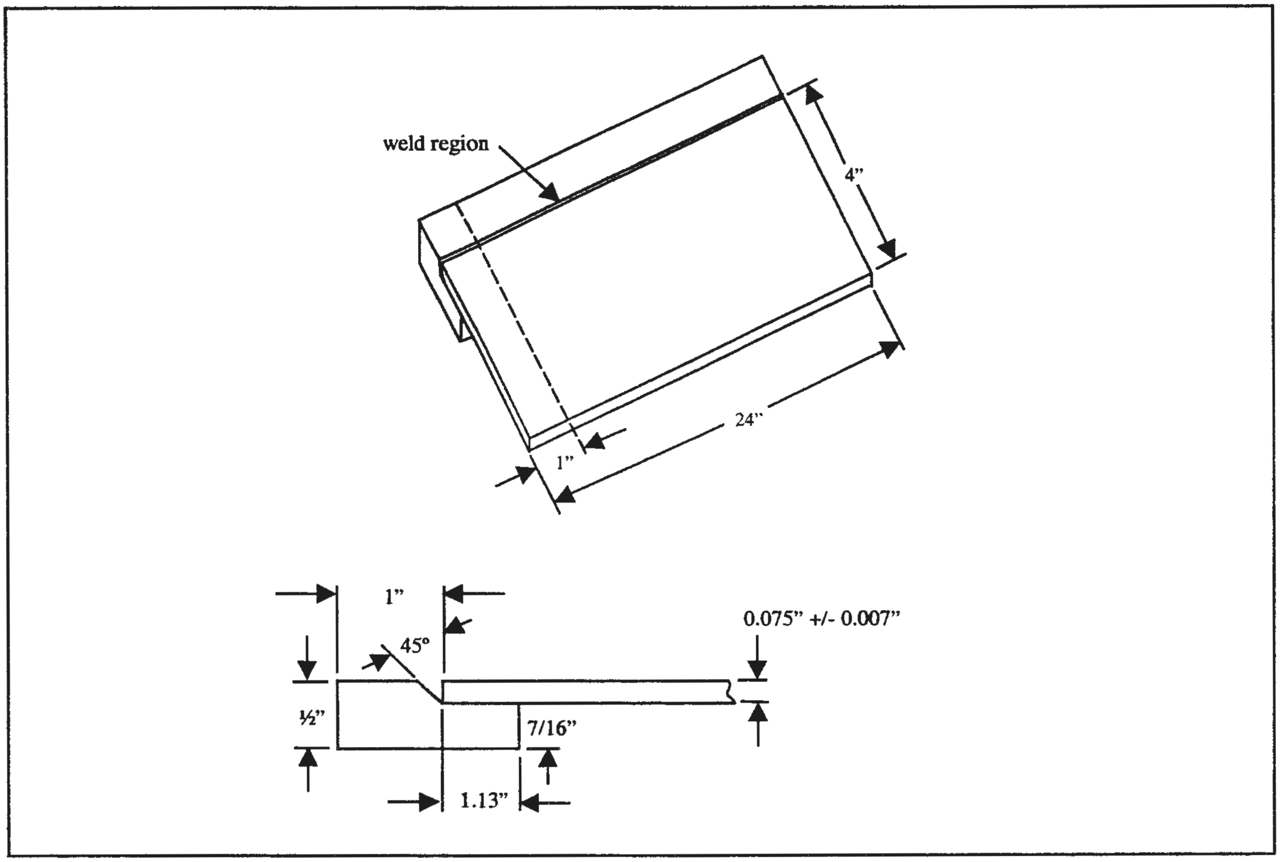

Figure 9. Schematic illustrating dimensions of fillet weld assembly.

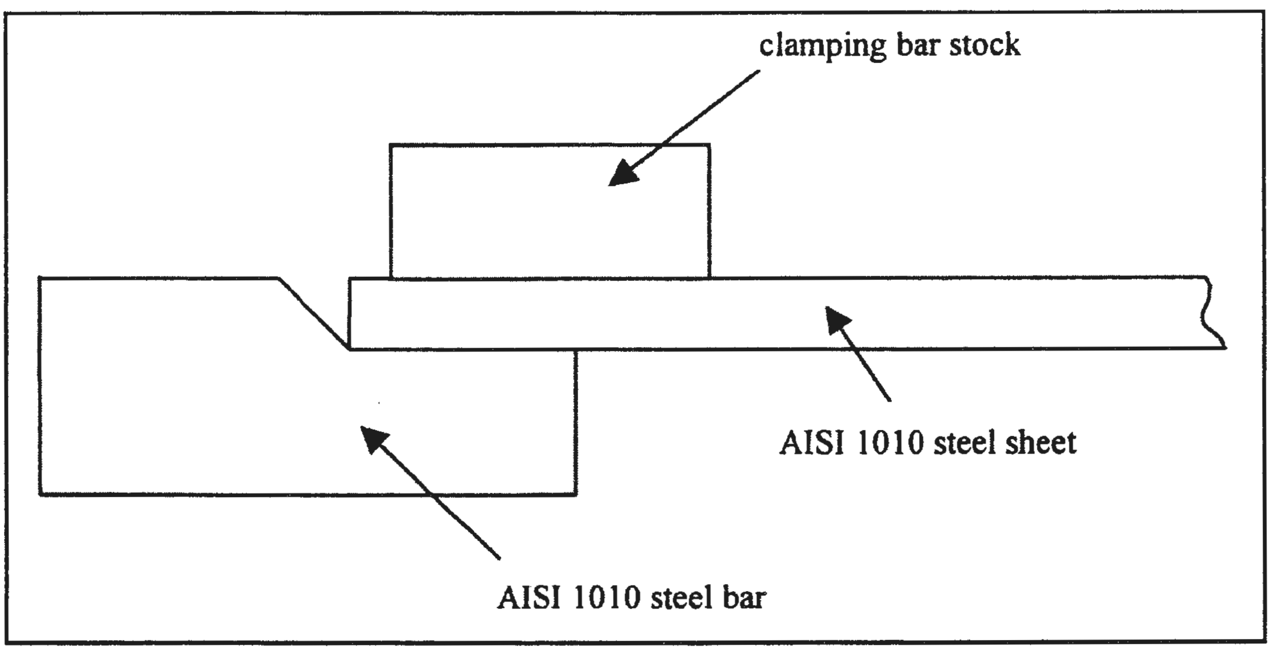

Figure 10. Method utilized by Aerotek to perform fillet weld.

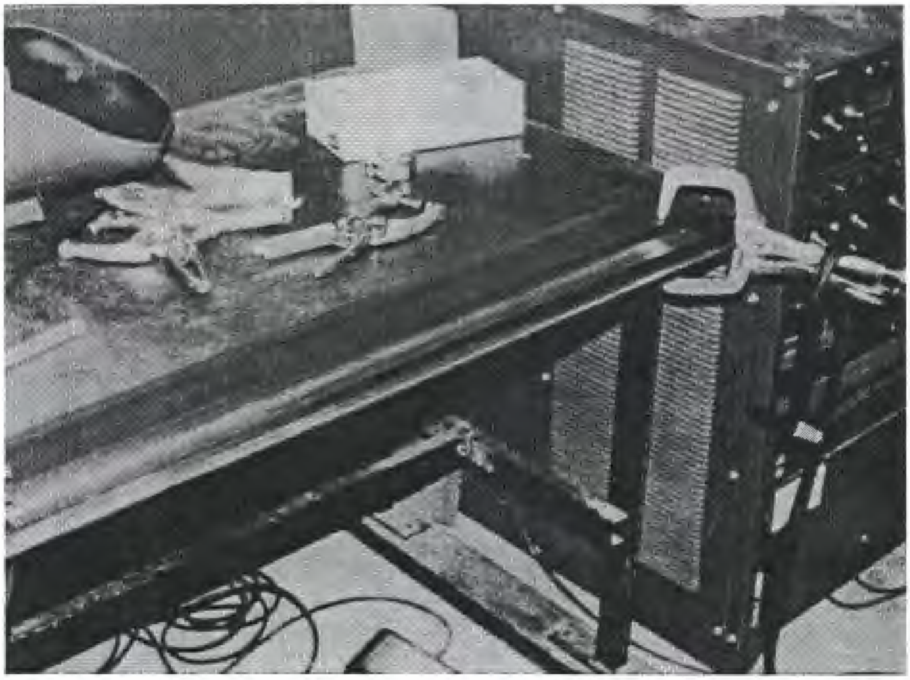

Figure 11. Photograph showing fillet weld assembly, as welded, at Aerotek.

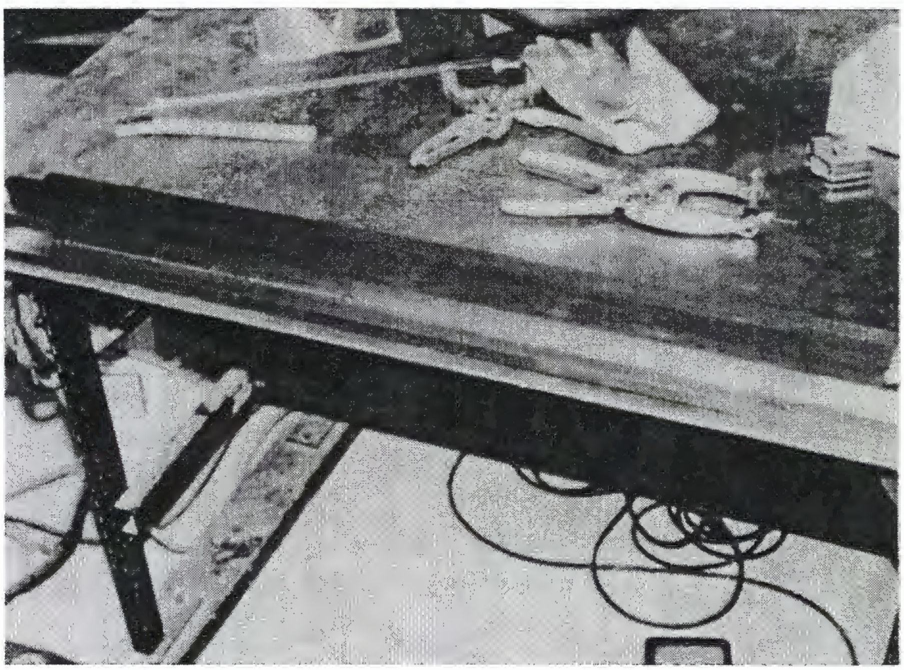

Figure 12. Photograph showing as-welded fillet weld assembly, from a different angle, at Aerotek.

6. Metallographic Examination

A specimen from each of the four types of welds was sectioned and prepared metallographically in accordance with ASTM E3 [10]. This was performed in order to inspect for the following characteristics:

- Overall quality,
- Location and depth of penetration,
- Structure of the weld metal and heat-affected zone,
- Extent of the heat-affected zone,
- Size of beads,
- Undercutting and overlapping,
- Cracks, and
- Porosity and inclusions.

The metallographic specimens were chosen to represent the beginning of a production run (spot weld specimen no. 1), the middle of production (plug weld specimen no. 11 and fillet specimen no. 15) and the end of a production run (seam weld specimen no. 24). This was performed in order to note any quality changes with elapsed time. The specimens were sectioned through the weld and mounted, as shown in Figures 13 and 14. Once mounted, the specimens were polished then etched with 1% nital etchant. Figures 16 through 19 show the etched cross section of the plug, spot, seam, and fillet welds, respectively.

The plug weld has no metallographic requirements as outlined in MIL-STD-2219. Figure 15 shows that the Aerotek plug weld specimen had a penetration of ~30%–40%. It should be noted the plug weld does not have to fill the hole completely, which was the case with the Aerotek weld (Figure 15). MIL-W-12332 lists the metallographic criteria that the spot and seam welds should conform to. The spot weld should demonstrate 30%–80% penetration into the thinner of the two sheets (each sheet was the same thickness). In general, penetration less than 30% leads to a weld that is referred to as "cold," in that not enough heat was generated in the weld zone [11]. This same reference states that penetration above 80% usually results in expulsion, excessive indentation, and rapid electrode wear. Figure 16 shows that the Aerotek weld conformed to this penetration criterion. Upon closer examination, however, the micrograph showed the interface between the two pieces of steel sheet that were spot welded. This indicated that the spot welds would most likely break in shear and fail to pull a nugget out of the parent material (indicative of a poor spot weld).

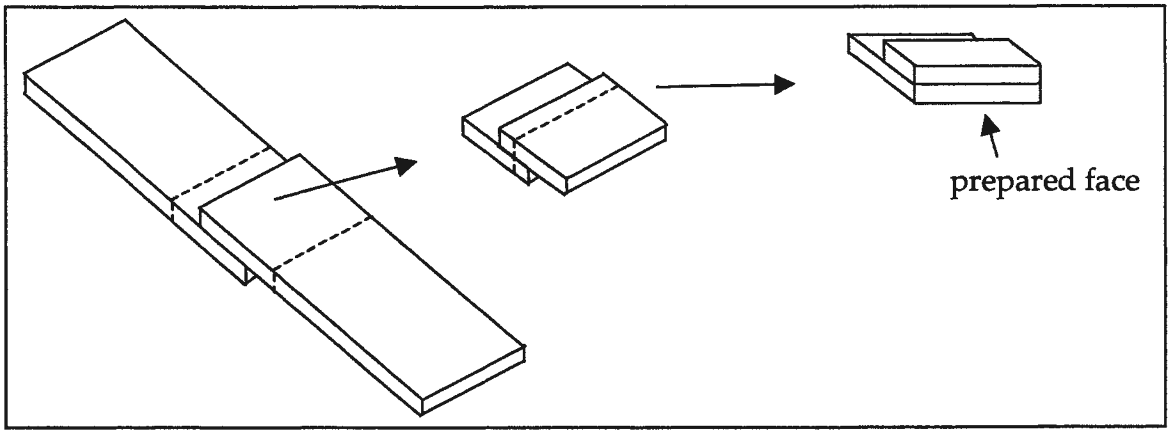

Figure 13. Schematic illustrating metallographic sectioning for the plug, spot, and seam weld specimens.

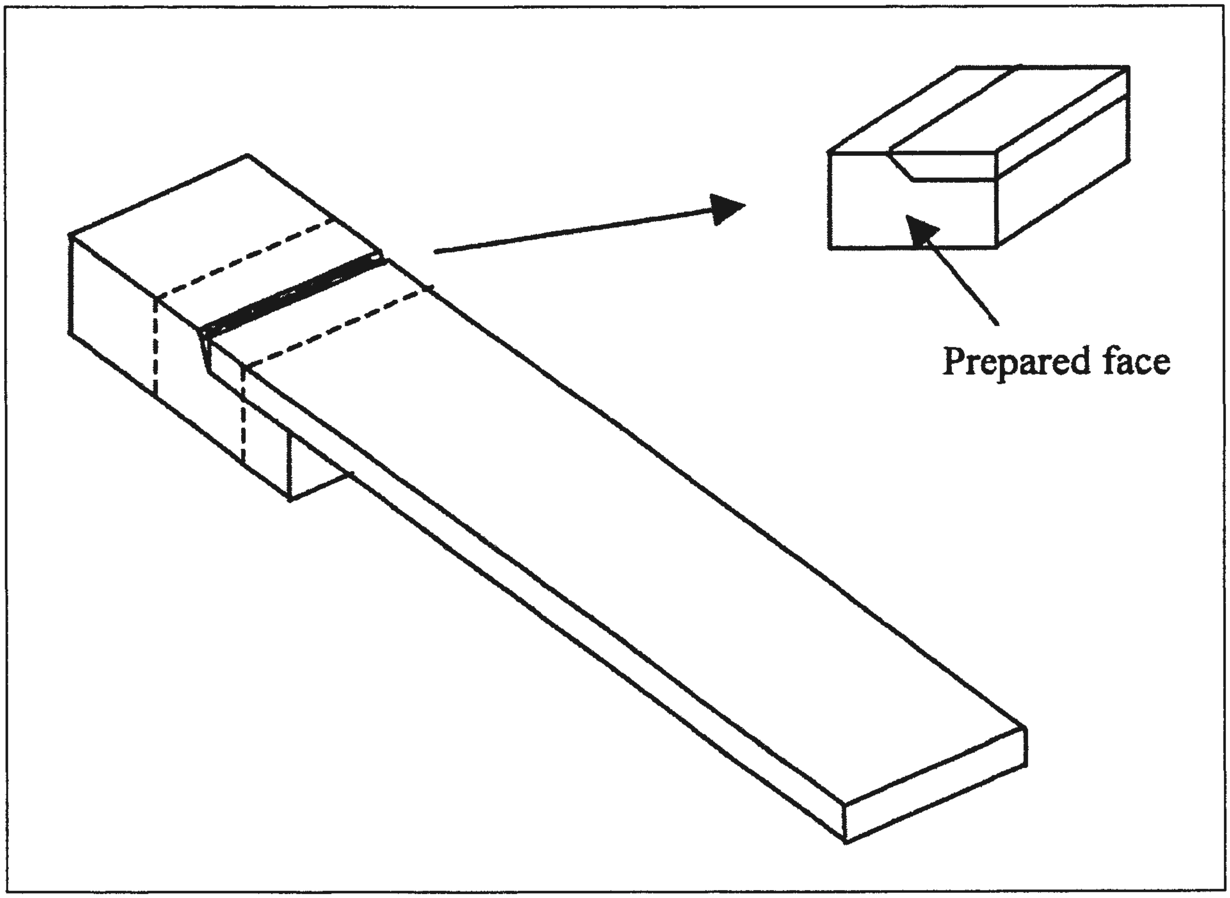

Figure 14. Schematic illustrating metallographic sectioning for the fillet weld specimen.

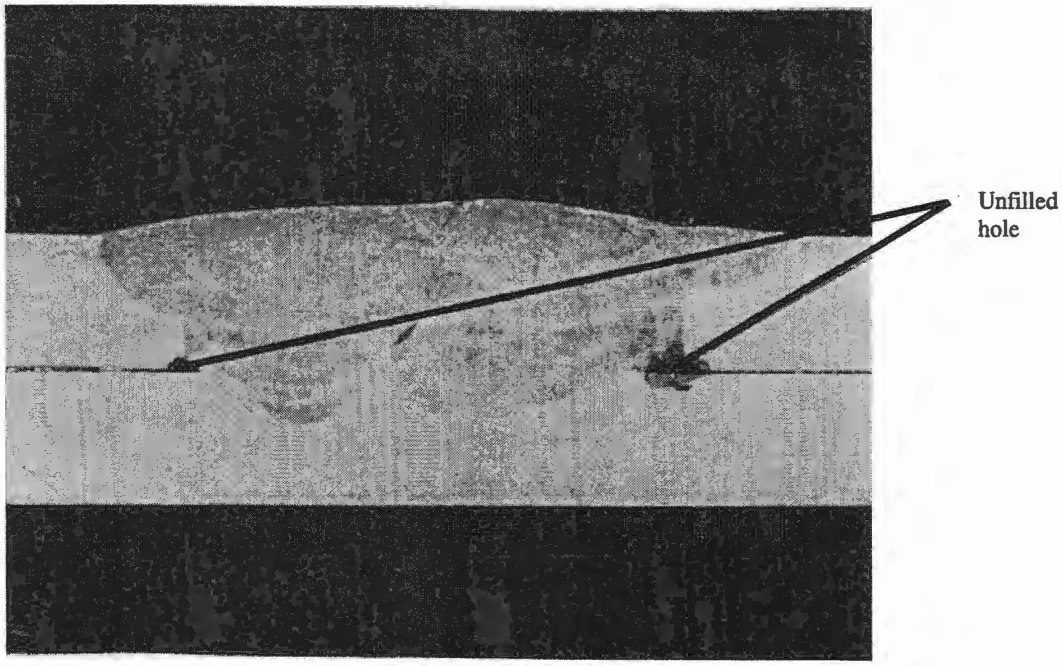

Figure 15. Cross section of a plug weld specimen etched with 1% nital etchant (note the unfilled hole); magnified 10×.

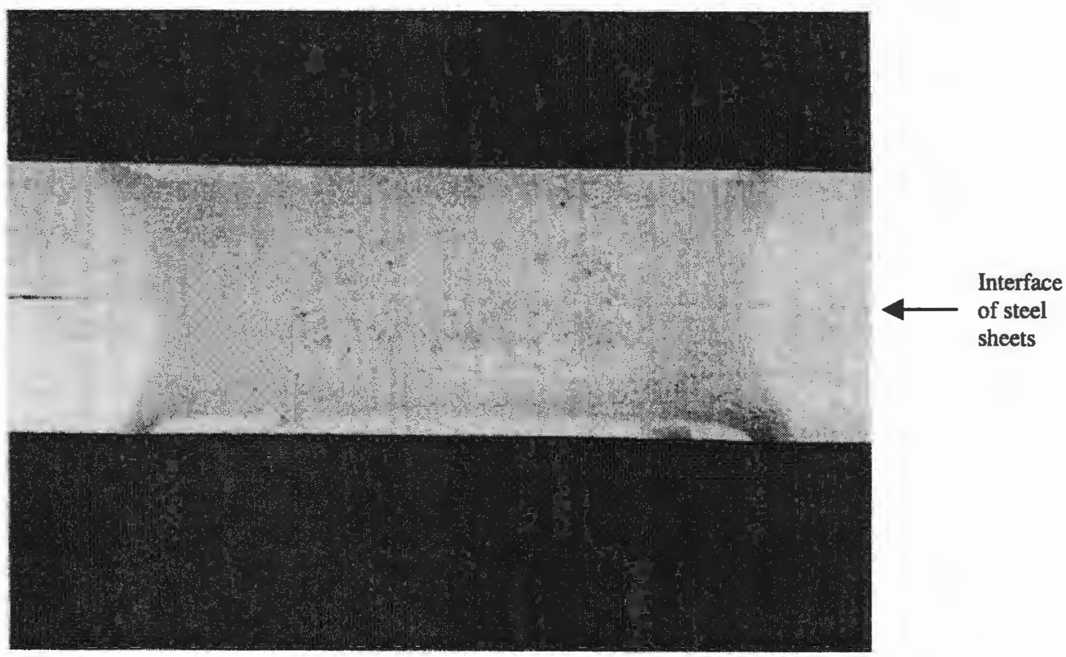

Figure 16. Cross section of a spot weld specimen etched with 1% nital etchant (note the interface of the two steel sheets present within the weld region); magnified 10×.

The seam weld is also required to have a penetration of 30%–80%. Figure 17 shows this criterion was satisfied by the Aerotek specimen. Finally, the two parts joined by the fillet weld must be on the same plane. The Aerotek specimen satisfied this criterion, as shown in Figure 18.

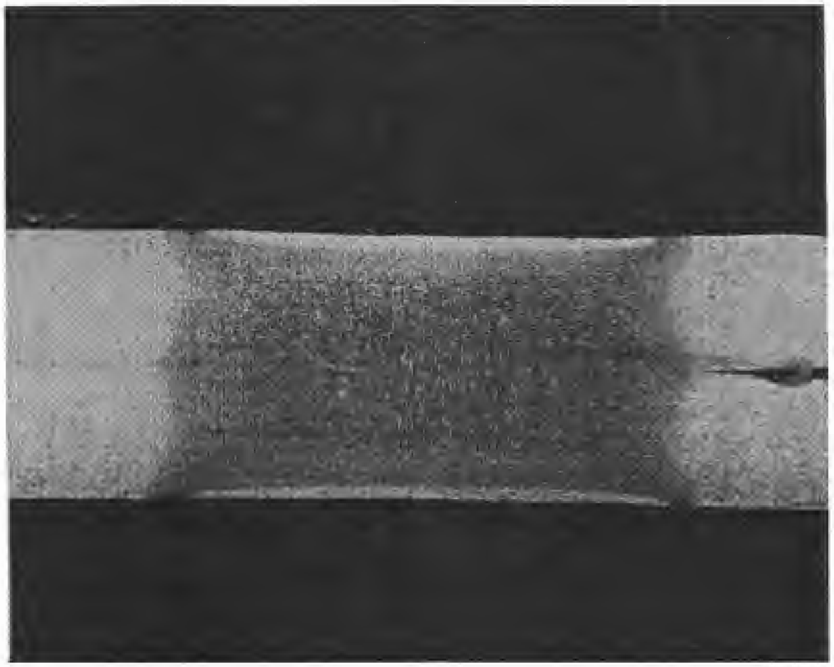

Figure 17. Cross section of a seam weld specimen etched with 1% nital etchant; magnified 10×.

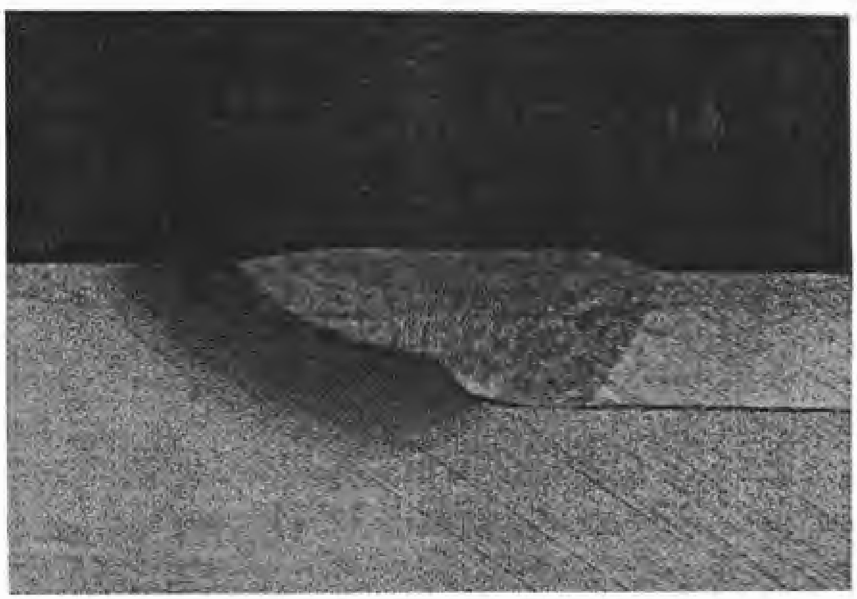

Figure 18. Cross section of a fillet weld specimen etched with 1% nital etchant; magnified 10×.

7. Mechanical Testing

It was reported that the bomb fin manufacturer believed that the 3200-lb requirement for the spot weld was rather excessive. The testing summarized herein was conducted in order to establish minimum weld strength requirements of each weld.

The test results for the remaining 23 specimens of each type of weld are listed in Tables 7–10 (the specimens from which the metallographic sample was sectioned could not be tested). A 50,000-lb capacity Instron universal electromechanical tensile testing machine was utilized for all testing. Hydraulic grips were used to secure the test specimens, with a gripping force of 750 psi for the plug, spot, and seam weld specimens and 600 psi for the fillet specimens. Testing was conducted at 70 °F and 50% relative humidity. The test parameters included 0.5-inch/minute pull rate, a 1-inch/minute chart speed, and a full-scale load range of 5000 lb. The specimens were subjected to a straight pull test, as shown in Figure 19. This tested the plug, spot, and seam welds in tensile shear and the fillet welds in tension. The mechanism of the tension-shear failure is described as follows [12]. The misalignment of the overlapping strips allows a couple to form, which causes bending near the weld; this bending increases progressively with the tensile load on the specimen, and the plane of the weld becomes inclined at an increasing angle to the line of the pull. This introduces a tearing action concentrated at two points on the circumference at opposite diameters of the weld. Thus, as the load increases, the test changes from pure shear to a complex system of shearing and tearing when failure occurs.

The objective was to fabricate these specimens in order to ensure the welding process was adequate through mechanical testing, followed by the fabrication of plug weld peel and spot weld peel specimens, based on lessons learned.

7.1 Plug Weld Tensile Shear Testing

Table 7 lists the test data acquired for the plug weld specimens. The specimen width, thickness, and plug weld diameter are listed as well as the maximum pull load. The specimens averaged a maximum load or 2315 lb, with a standard deviation of 165 lb. Most plug welds that were subjected to this testing formed a nugget upon failure. In a few cases, however, the nugget ripped the steel around the weld, thereby making the nugget immeasurable. Figure 20 shows a typical "male" and "female" nugget failure, while Figure 21 shows a specimen in which the nugget ripped the steel. A tensile shear test in which the plug weld forms a nugget upon failure is desirable, as it verifies an adequate penetration of the plug weld. It is also desirable if the steel around the nugget rips, as this also verifies adequate weld penetration. This is substantiated by the governing specification of MIL-W-12332 which states that, "failures at or outside the periphery of the weld area shall be considered evidence that the welds are satisfactory."

Table 7. Results of plug weld tensile shear testing – first trial.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Max. Load (lb)	Break Comments	Nugget Diameter (Measured on Hole) (in)
1	1.0020	0.073	0.25	Metallographic Examination		
2	1.0000	0.073	0.25	2250	N, B	3/16 × 5/32
3	1.0020	0.073	0.25	2325	N, B	7/32 × 5/32
4	1.0000	0.073	0.25	2500	N, B	NA
5	1.0030	0.073	0.25	2350	N, B	7/32 × 3/16
6	1.0020	0.073	0.25	2480	N, B	1/8 × 3/32
7	1.0025	0.073	0.25	1870	N, B	3/16 × 5/32
8	1.0015	0.073	0.25	2180	NN, WS, B	NA
9	1.0000	0.073	0.25	2380	N, B	7/32 × 5/32
10	1.0015	0.073	0.25	2525	N, B	NA
11	1.0005	0.073	0.25	2165	N, B	1/16
12	1.0010	0.073	0.25	2200	N, B	3/32
13	1.0020	0.073	0.25	2250	N, B	3/16 × 5/32
14	1.0020	0.073	0.25	2375	N, B	5/32 × 1/8
15	1.0010	0.073	0.25	2175	NN, WS, B	NA
16	1.0015	0.073	0.25	2250	N, B	5/32 × 1/8
17	1.0030	0.073	0.25	2260	N, B	1/8 × 3/32
18	1.0010	0.073	0.25	2275	N, B	7/32 × 3/16
19	1.0020	0.073	0.25	2250	N, B	3/16 × 5/32
20	1.0020	0.073	0.25	2740	N, B	NA
21	1.0020	0.073	0.25	2345	N, B	3/16 × 5/32
22	1.0010	0.073	0.25	2390	N, B	7/32 × 5/32
23	1.0015	0.073	0.25	2400	N, B	7/32 × 3/16
24	1.0025	0.073	0.25	2315	N, B	5/32 × 1/8
Average	—	—	—	2315	—	—
Std. Dev.	—	—	—	165	—	—

Notes: N = Nugget of weld was pulled out of specimen as a result of testing.
B = Burn marks were noted under the overlap interface, encircling the weld with an approximate 1/4-inch diameter.
NN = No nugget was formed as a result of testing.
WS = The weld sheared as a result of testing.
NA = Not applicable (nugget was immeasurable).

Two plug weld failures occurred such that no nugget was formed, however, and the weld had simply sheared in half. An example of this type of failure is shown in Figure 22. It is undesirable for a plug weld to fail in shear, as it shows a lack of weld penetration and indicates a poor-quality plug weld. There was no apparent correlation between the order in which the specimens were produced vs. the different types of failures noted.

Discoloration most likely caused by burning was noted under the 1-inch overlap interface of each specimen, as noted in Figure 22. The burn mark encircled the weld and emanated from the weld with a radius of ~1/4 inch. An increased current could have caused the burning during the welding process. There was also the presence of an oily film under the interface, which was the light oil placed on the specimens before shipment to ARL to inhibit corrosion.

Table 8. Results of spot weld tensile shear testing – first trial.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Max. Load (lb)	Break Comments	Nugget Diameter
1	1.0040	0.073	0.30	2150	NN, WS	NA
2	1.0030	0.073	0.30	2120	NN, WS	NA
3	1.0040	0.073	0.30	2060	NN, WS	NA
4	1.0020	0.073	0.30	2075	NN, WS	NA
5	1.0010	0.073	0.30	2060	NN, WS	NA
6	1.0000	0.073	0.30	1925	NN, WS	NA
7	1.0010	0.073	0.30	2075	NN, WS	NA
8	1.0040	0.073	0.30	2150	NN, WS	NA
9	1.0030	0.073	0.30	1995	NN, WS	NA
10	1.0010	0.073	0.30	2110	NN, WS	NA
11	1.0010	0.073	0.30	Metallographic Examination		
12	1.0010	0.073	0.30	2100	NN, WS	NA
13	1.0030	0.073	0.30	2080	NN, WS	NA
14	1.0010	0.073	0.30	2125	NN, WS	NA
15	1.0010	0.073	0.30	2070	NN, WS	NA
16	1.0030	0.073	0.30	2120	NN, WS	NA
17	1.0020	0.073	0.30	2180	NN, WS	NA
18	1.0010	0.073	0.30	2085	NN, WS	NA
19	1.0020	0.073	0.30	2200	NN, WS	NA
20	1.0020	0.073	0.30	2160	NN, WS	NA
21	1.0010	0.073	0.30	1930	NN, WS	NA
22	1.0020	0.073	0.30	2125	NN, WS	NA
23	1.0030	0.073	0.30	1950	NN, WS	NA
24	1.0020	0.073	0.30	2045	NN, WS	NA
Average	—	—	—	2080	—	—
Std. Dev.	—	—	—	75	—	—

Notes: NN = No nugget was formed as a result of testing.
WS = The weld sheared as a result of testing.
NA = Not applicable.

7.2 Spot Weld Tensile Shear Testing

The test data for the spot welds including the specimen width, thickness, spot weld diameter, and maximum tensile shear load are listed in Table 8. The specimens averaged a maximum load of 2080 lb with a standard deviation of 75 lb. Each spot weld specimen failed such that the weld sheared and no nugget was formed. This was indicative of a poor spot weld in which complete melting did not occur (this was verified by the interface line noted during metallographic examination). A typical spot weld specimen failure is shown in Figure 23. Similar to the plug weld specimens, oil was also present under the 1-inch overlap of these specimens. The burning previously noted around the plug welds was not noted with these spot welds.

Table 9. Results of seam weld tensile shear testing.

ID	Width (in)	Thickness (in)	Maximum Load (lb)	Break Comments
1	1.0020	0.073	3250	NN, WS
2	1.0015	0.073	3240	NN, WS
3	1.0010	0.073	3250	NN, WS
4	1.0030	0.073	3275	NN, WS
5	1.0010	0.073	3280	NN, WS
6	1.0000	0.073	3245	NN, WS
7	1.0015	0.073	3260	NN, WS
8	1.0000	0.073	3250	NN, WS
9	1.0015	0.073	3290	NN, WS
10	1.0025	0.073	3300	NN, WS
11	1.0010	0.073	3275	NN, WS
12	1.0010	0.073	3280	NN, WS
13	1.0010	0.073	3280	NN, WS
14	1.0010	0.073	3240	NN, WS
15	1.0020	0.073	3280	NN, WS
16	1.0015	0.073	3270	NN, WS
17	1.0020	0.073	3270	NN, WS
18	1.0025	0.073	3290	NN, WS
19	1.0020	0.073	3290	NN, WS
20	1.0030	0.073	3310	NN, WS
21	1.0020	0.073	3295	NN, WS
22	1.0020	0.073	3290	NN, WS
23	1.0020	0.073	3280	NN, WS
24	1.0010	0.073	Metallographic Examination	
Average	—	—	3270	—
Std. Dev.	—	—	20	—

Notes: NN = No nugget was formed as a result of testing.
WS = The weld sheared as a result of testing.

7.3 Seam Weld Tensile Shear Testing

The test data for the seam welds including the specimen width, thickness, and maximum tensile shear load are listed in Table 9. These specimens averaged a maximum load of 3270 lb, with a standard deviation of 20 lb. Each seam weld specimen failed in the parent material, far from the weld region (i.e., not in the heat-affected zone). This was indicative of a high-quality seam weld. A typical seam weld specimen failure is shown in Figure 24.

7.4 Fillet Weld Tension Testing

The test data for the fillet weld specimens are listed in Table 10. This table lists the specimen width, thickness, and maximum tensile load. The specimens averaged a maximum load of 3270 lb, with a standard deviation of 20 lb. Similar to the seam weld specimens, each fillet weld specimen failed in the parent sheet material, far from the weld region (i.e., not in the heat-affected zone). A typical fillet weld specimen failure is shown in Figure 25.

Table 10. Results of fillet weld tensile testing.

ID	Width (in)	Thickness (in)	Maximum Load (lb)	Break Comments
1	1.0010	0.073	3295	PM
2	1.0000	0.073	3270	PM
3	1.0010	0.073	3290	PM
4	1.0010	0.073	3280	PM
5	1.0000	0.073	3265	PM
6	1.0000	0.073	3280	PM
7	1.0020	0.073	3275	PM
8	1.0020	0.073	3300	PM
9	1.0020	0.073	3300	PM
10	1.0010	0.073	3300	PM
11	1.0030	0.073	3300	PM
12	1.0025	0.073	3295	PM
13	1.0015	0.073	3280	PM
14	1.0010	0.073	3280	PM
15	1.0010	0.073	Metallographic Examination	
16	1.0020	0.073	3280	PM
17	1.0020	0.073	3295	PM
18	1.0015	0.073	3300	PM
19	1.0015	0.073	3300	PM
20	1.0010	0.073	3270	PM
21	1.0000	0.073	3250	PM
22	1.0015	0.073	3290	PM
23	1.0030	0.073	3285	PM
24	1.0020	0.073	3290	PM
Average	—	—	3290	—
Std. Dev.	—	—	15	—

Note: PM = The failure occurred within the parent material, far from the weld (not in the heat-affected zone).

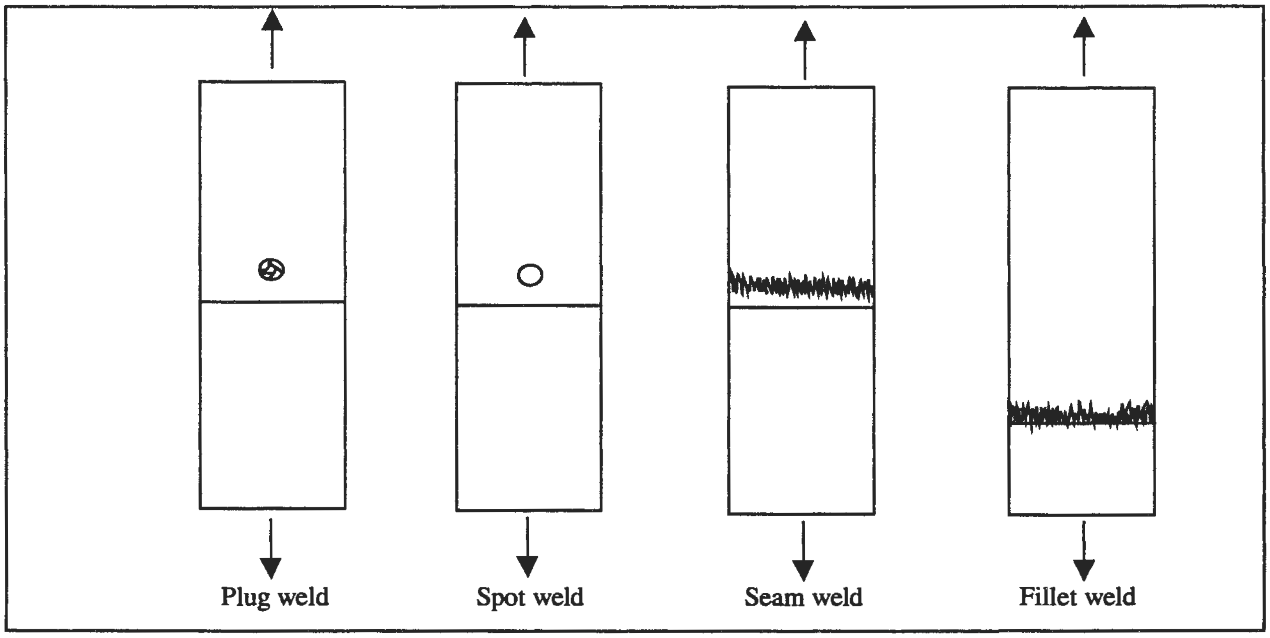

Figure 19. Schematic illustrating pull test direction for each type of weld specimen.

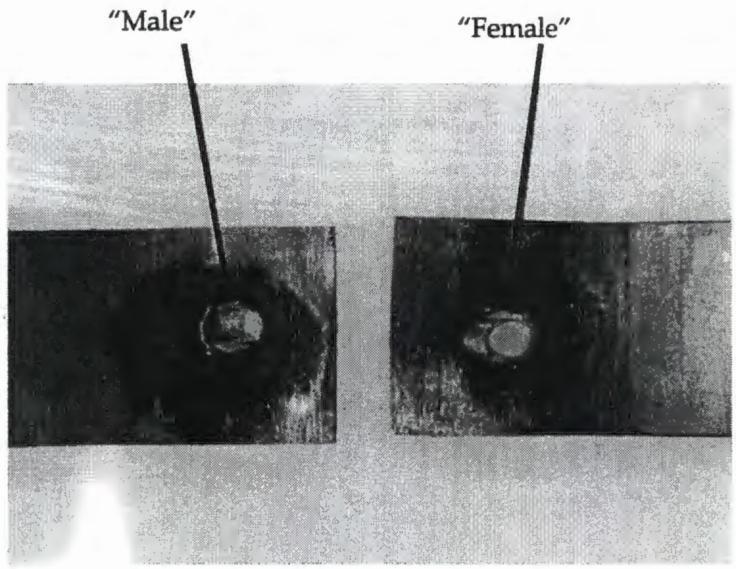

Figure 20. Typical "male" and "female" plug weld nugget failure; magnified 1×.

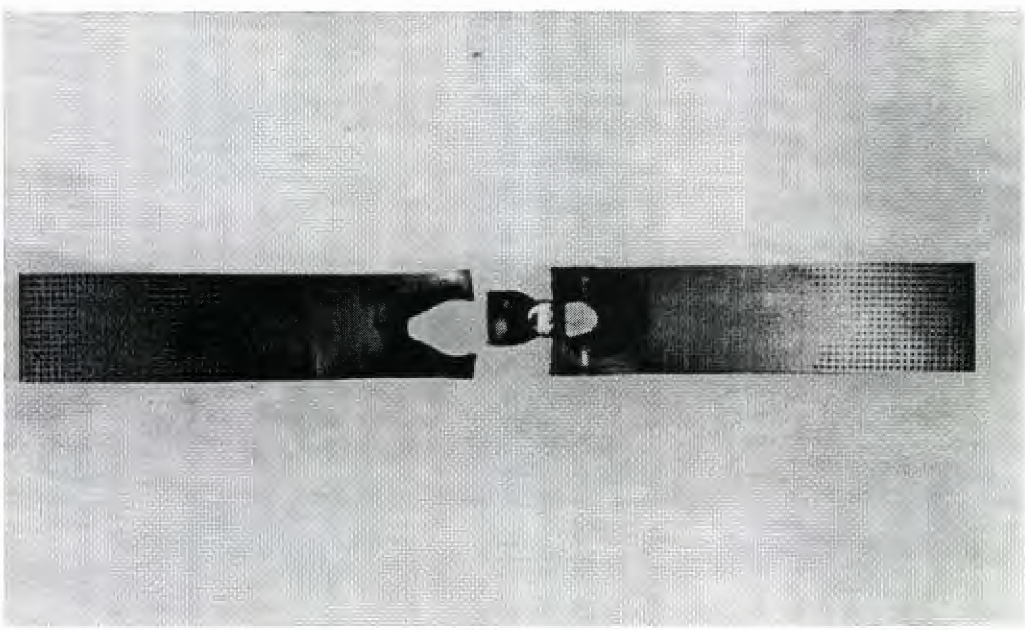

Figure 21. Plug weld failure in which a nugget tore steel around the weld region; reduced 50%.

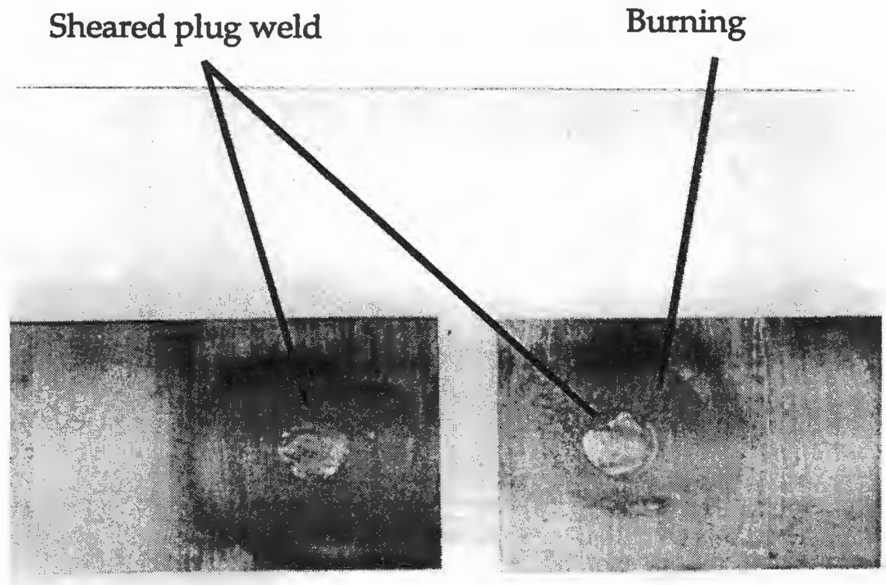

Figure 22. A macrograph showing a representative sheared plug weld; magnified 1×.

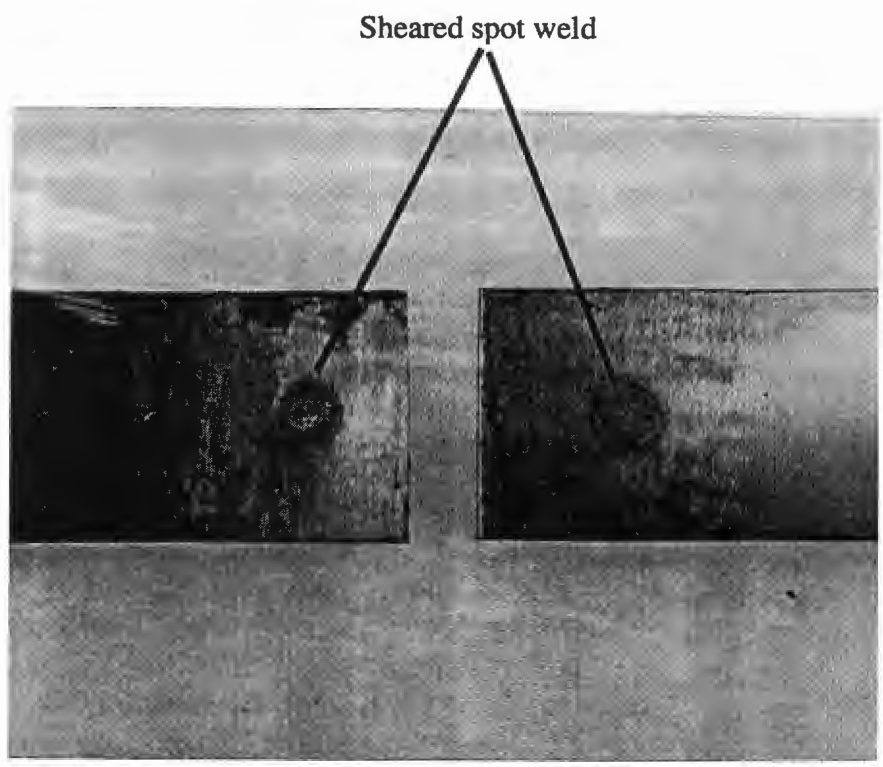

Figure 23. A typical spot weld shear failure; magnified 1×.

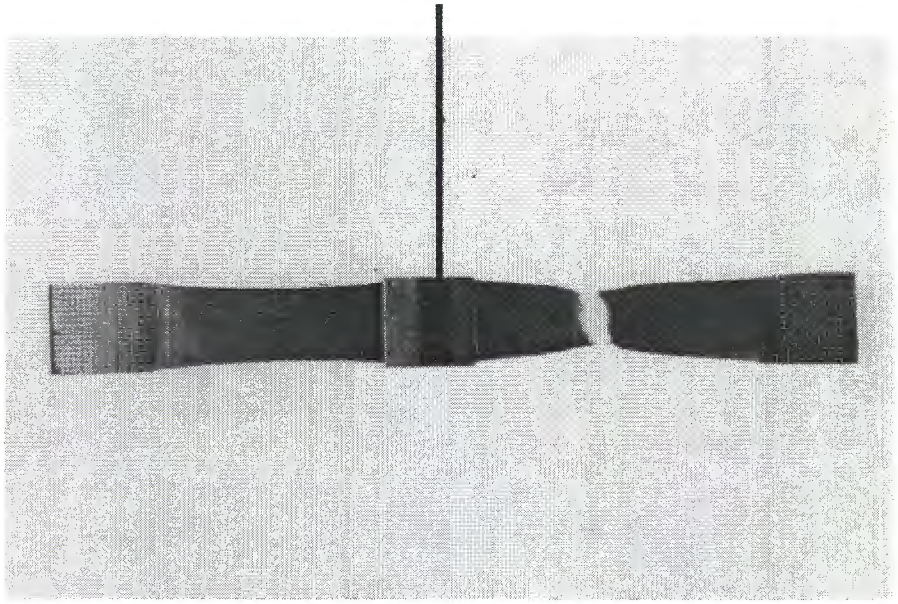

Figure 24. A typical seam weld failure; reduced 50%.

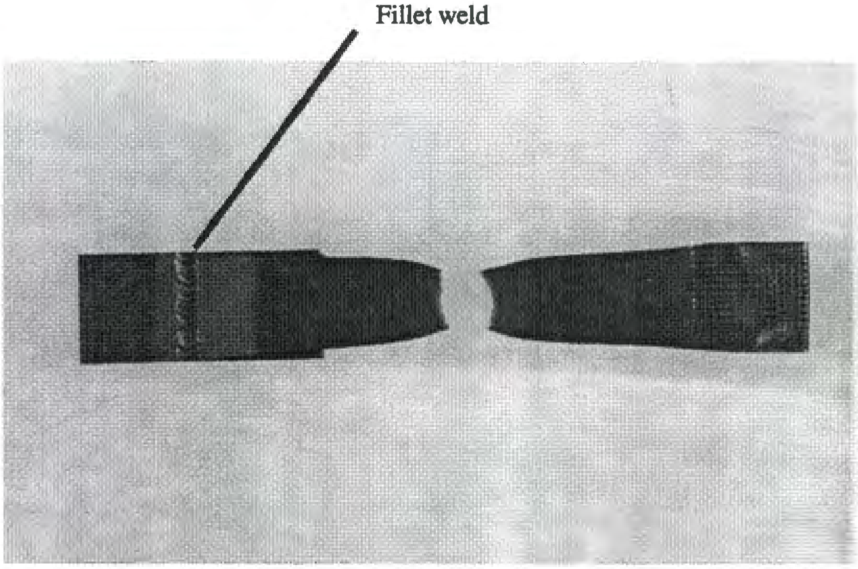

Figure 25. A typical fillet weld failure; reduced 50%.

8. Further Mechanical Testing

Aerotek fabricated the following additional specimens: 24 plug weld tensile shear, 24 plug weld peel, 24 spot weld tensile shear, and 24 spot weld peel. These specimens were fabricated incorporating a higher amperage to increase the weld penetration (from a previous amperage range between 93 and 100 A to a range of 97–115 A). The peel specimens were fabricated since it was required for the spot welds [4] and was a simple and low-cost method of evaluating the penetration of the spot and plug welds.

The physical dimensions of these additional specimens remained similar to the previous specimens discussed earlier. Aerotek also altered the process in which the plug weld specimens were welded. Unlike the previous trial run, in which the backside was accessed, Aerotek was limited to only frontal access of the weld. This simulated actual bomb fin production restrictions encountered by the bomb fin manufacturer. No restrictions were imposed on the spot weld, as contractors have access to both sides of the spar during welding. In addition, Aerotek treated these specimens as a production run, similar to the method most likely incorporated by the bomb fin manufacturer. The parameters utilized by Aerotek for all improved plug weld specimens are listed in Appendix F. The improved spot weld parameters are listed in Appendix G. A typical peel specimen is shown in Figure 26.

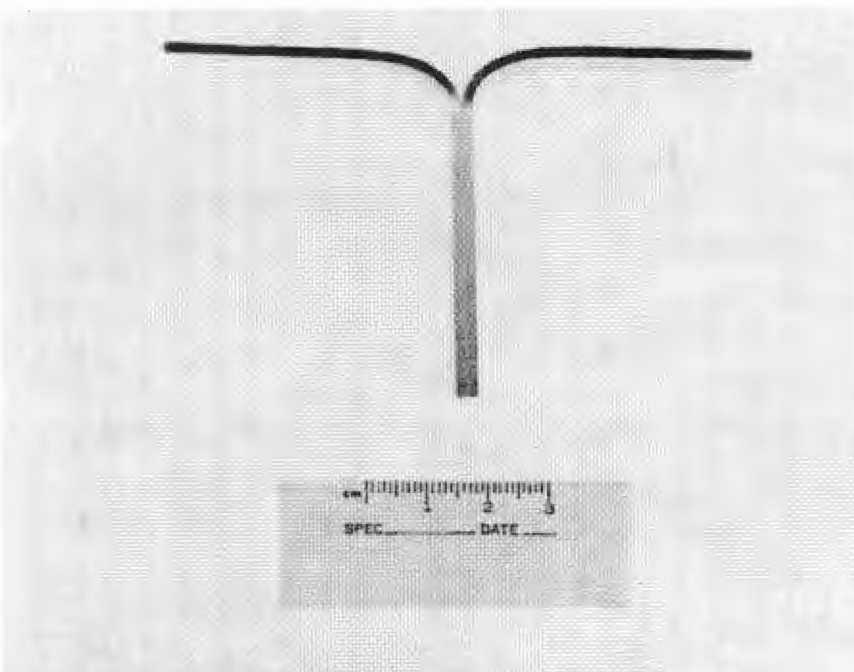

Figure 26. A typical peel test specimen; reduced 50%.

The last specimen (no. 26) from each production run was sectioned, mounted, and metallographically prepared such that the weld region could be examined. The plug weld penetration had improved and showed at least 50% penetration (as opposed to ~30% penetration previously). This indicated the increased amperage utilized by Aerotek led to increased penetration, which subsequently led to a stronger weld. The seam weld did not display the interface previously noted. A macrograph of the weld region of the plug tensile shear, plug peel, spot tensile, and spot peel specimens are shown in Figures 27–30.

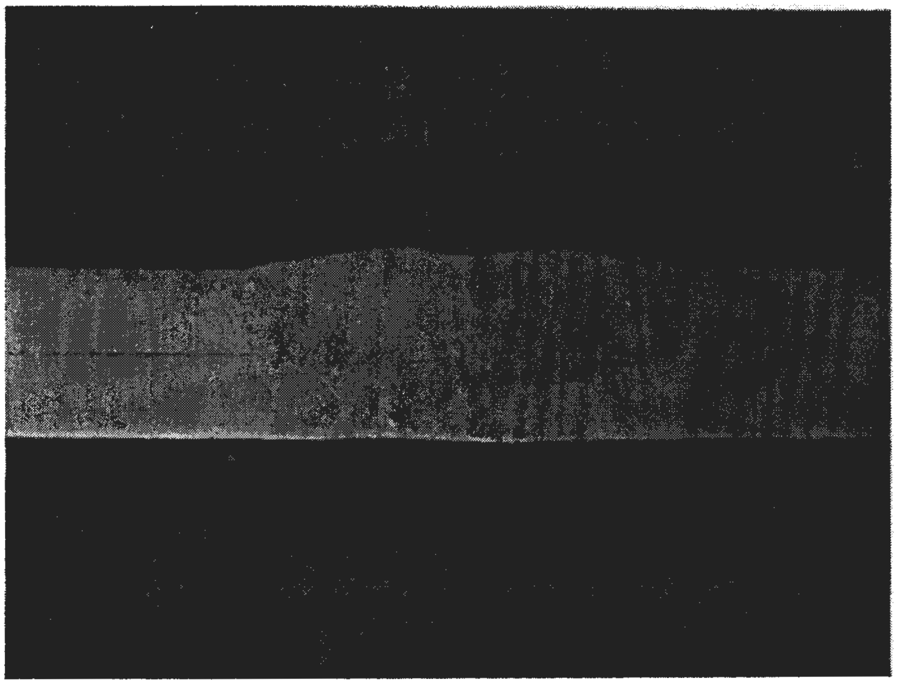

Figure 27. Macrograph of a typical improved plug weld tensile shear specimen; magnified 9×, etchant: 1% nital.

8.1 Additional Plug Weld Tensile Shear Testing

Table 11 lists the test data acquired from the additional tensile shear testing of the plug weld specimens. The specimens averaged a maximum pull load of 2999 lb, with a standard deviation of 76 lb. This was a marked improvement over the previous plug weld shear test results (compared to the average of 2315 lb achieved by the previous specimens). The parent material failed far from the weld region in each instance. An example of this typical failure is shown in Figure 31.

8.2 Plug Weld Peel Testing

Table 12 contains the test data acquired from plug weld peel testing. The specimens averaged a maximum peel load of 821 lb, with a standard deviation of 69 lb. The samples failed such that the metal tore around the weld region (heat-affected zone), creating an immeasurable nugget. This type of failure was acceptable and is shown in Figure 32.

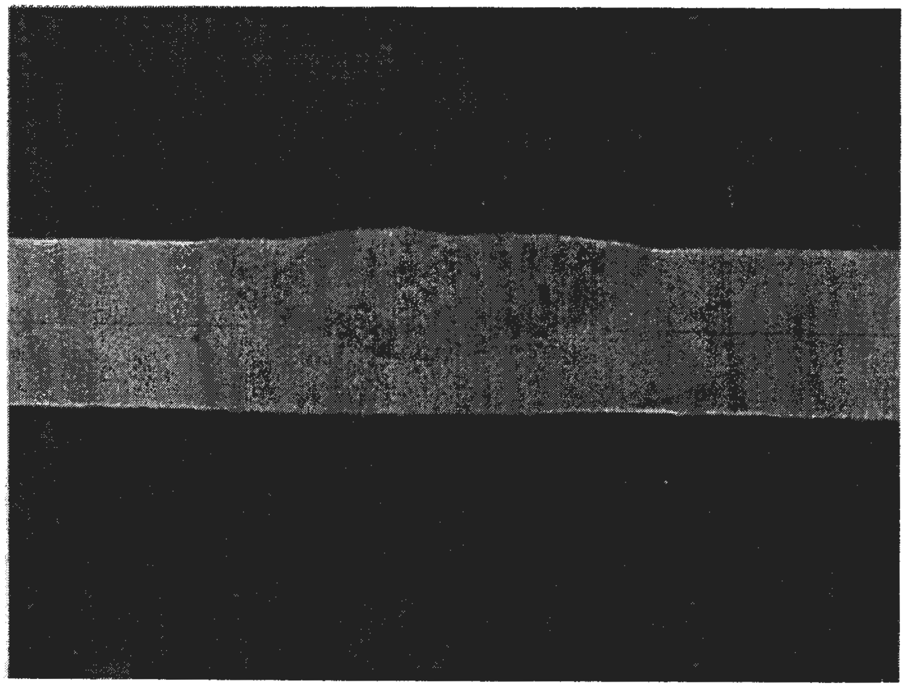

Figure 28. Macrograph of a plug weld peel specimen welded using improved conditions by Aerotek; magnified 9×, etchant: 1% nital.

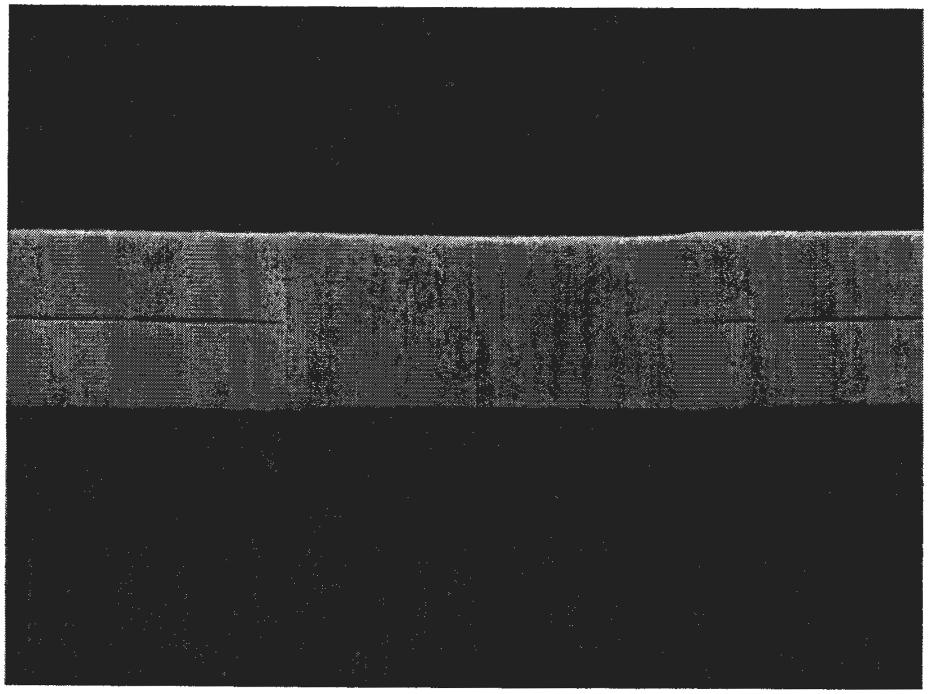

Figure 29. Macrograph of a typical improved spot weld tensile shear specimen; magnified 9×, etchant: 1% nital.

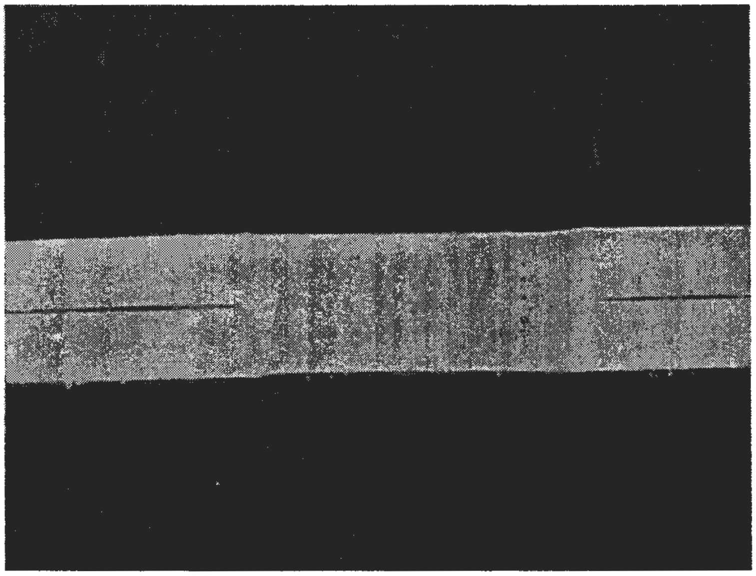

Figure 30. Macrograph of a spot weld peel specimen welded using improved conditions by Aerotek; magnified 9×, etchant: 1% nital.

Table 11. Results of plug weld tensile shear testing – improved method.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Maximum Load (lb)	Break Comments	Nugget Diameter (Measured on Hole)
1	1.0015	0.074	0.25	2900	PM	NA
2	1.0020	0.074	0.25	2825	PM	NA
3	1.0015	0.074	0.25	2900	PM	NA
4	1.0040	0.074	0.25	2950	PM	NA
5	1.0010	0.074	0.25	3050	PM	NA
6	1.0030	0.074	0.25	2990	PM	NA
7	1.0020	0.074	0.25	2980	PM	NA
8	1.0010	0.074	0.25	3025	PM	NA
9	1.0040	0.074	0.25	3100	PM	NA
10	0.9930	0.074	0.25	2920	PM	NA
11	1.0040	0.074	0.25	3015	PM	NA
12	0.9970	0.074	0.25	3030	PM	NA
13	1.0010	0.074	0.25	2965	PM	NA
14	1.0020	0.074	0.25	3030	PM	NA
15	1.0025	0.074	0.25	3100	PM	NA
16	1.0020	0.074	0.25	3000	PM	NA
17	1.0010	0.074	0.25	3000	PM	NA
18	1.0020	0.074	0.25	3075	PM	NA
19	1.0025	0.074	0.25	2975	PM	NA
20	1.0010	0.074	0.25	3090	PM	NA
21	1.0015	0.074	0.25	3140	PM	NA
22	1.0020	0.074	0.25	2925	PM	NA
23	1.0020	0.074	0.25	3000	PM	NA
24	1.0030	0.074	0.25	Metallographic Examination		
Average	—	—	—	2999	—	—
Std. Dev.	—	—	—	76	—	—

Notes: PM = The failure occurred within the parent material, far from the weld (not in the heat-affected zone).
NA = Not applicable.

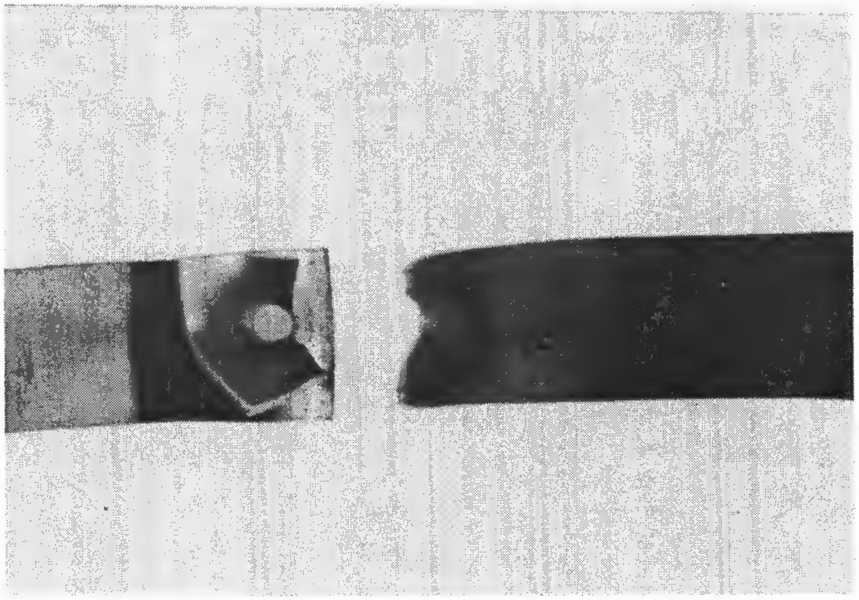

Figure 31. Typical failure of an improved plug weld tensile shear specimen. Failure occurred in the parent material; magnified 1×.

Table 12. Results of plug weld peel testing.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Maximum Load (lb)	Break Comments	Nugget Diameter (Measured on Hole)
1	1.0015	0.073	0.25	680	MT, NI	NA
2	1.0030	0.073	0.25	865	MT, NI	NA
3	1.0025	0.073	0.25	850	MT, NI	NA
4	1.0020	0.073	0.25	760	MT, NI	NA
5	1.0010	0.073	0.25	850	MT, NI	NA
6	1.0030	0.073	0.25	925	MT, NI	NA
7	1.0015	0.073	0.25	725	MT, NI	NA
8	1.0020	0.073	0.25	890	MT, NI	NA
9	1.0025	0.073	0.25	895	MT, NI	NA
10	1.0015	0.073	0.25	835	MT, NI	NA
11	1.0020	0.073	0.25	840	MT, NI	NA
12	1.0015	0.073	0.25	740	MT, NI	NA
13	1.0005	0.073	0.25	875	MT, NI	NA
14	1.0010	0.073	0.25	710	MT, NI	NA
15	1.0015	0.073	0.25	880	MT, NI	NA
16	1.0030	0.073	0.25	720	MT, NI	NA
17	1.0025	0.073	0.25	865	MT, NI	NA
18	1.0015	0.073	0.25	840	MT, NI	NA
19	1.0015	0.073	0.25	760	MT, NI	NA
20	0.9900	0.073	0.25	800	MT, NI	NA
21	0.9950	0.073	0.25	885	MT, NI	NA
22	1.0015	0.073	0.25	850	MT, NI	NA
23	1.0010	0.073	0.25	835	MT, NI	NA
24	1.0020	0.073	0.25	Metallographic Examination		
Average	—	—	—	821	—	—
Std. Dev.	—	—	—	69	—	—

Notes: MT = Parent metal tore around the weld.
NI = Nugget was immeasurable.
NA = Not applicable.

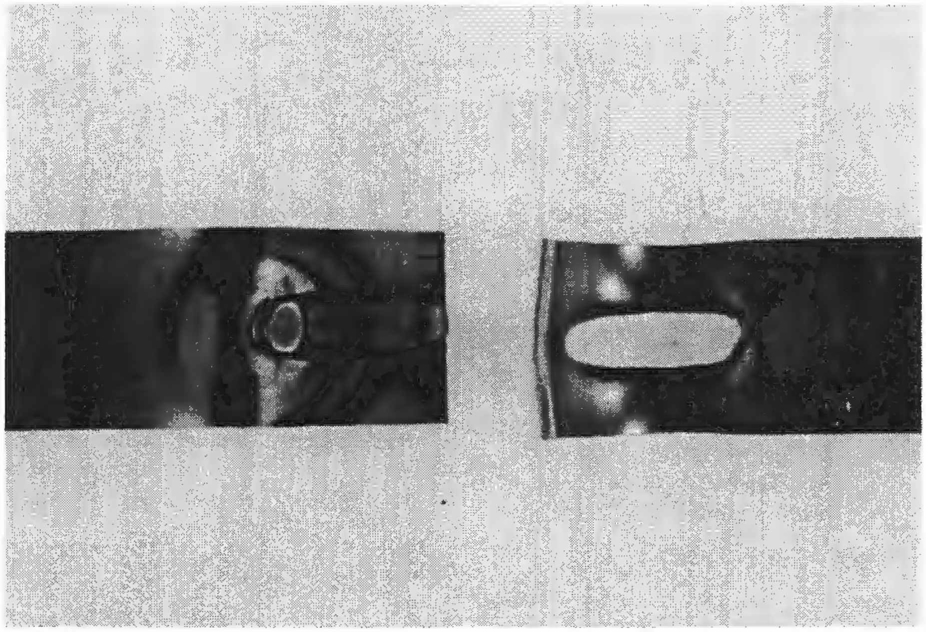

Figure 32. Typical failure of a plug weld peel specimen welded under improved conditions. Failure occurred by metal tearing initiated within the heat-affected zone; magnified 1×.

8.3 Additional Spot Weld Tensile Shear Testing

The results of the additional spot weld tensile shear tests are listed in Table 13. The specimens averaged a maximum pull load of 2897 lb, with a standard deviation of 96 lb. This was also a marked improvement over the previous spot weld tensile shear testing results (compared to the average of 2080 lb achieved previously). Four different failure modes were noted during testing, most likely due to inconsistencies during the welding process. The higher maximum loads corresponded to a failure mode which occurred in the parent material far from the heat-affected zone. The next highest loads corresponded to failures in which the metal tore around the weld, through the heat-affected zone. The formation of a weld nugget corresponded to the next highest load. Finally, the lowest loads corresponded to failures in which the weld bead had sheared in half, indicating poor penetration. Each of these failure modes is displayed in Figures 33–36. The specimens that were produced early in the production run achieved higher maximum loads than the specimens produced later in the run.

Table 13. Results of spot weld tensile shear testing – improved method.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Maximum Load (lb)	Break Comments	Nugget Diameter
1	1.0015	0.075	0.30	3025	PM	NA
2	1.0030	0.075	0.30	2970	PM	NA
3	1.0020	0.075	0.30	3000	PM	NA
4	1.0010	0.075	0.30	3000	PM	NA
5	1.0025	0.075	0.30	3000	PM	NA
6	1.0020	0.075	0.30	3000	PM	NA
7	1.0020	0.075	0.30	3000	PM	NA
8	1.0010	0.075	0.30	2990	PM	NA
9	0.9980	0.075	0.30	2900	PM	NA
10	1.0000	0.075	0.30	2800	NN, WS	NA
11	1.0000	0.075	0.30	2900	PM	NA
12	1.0000	0.075	0.30	2850	PM	NA
13	1.0020	0.075	0.30	2900	PM	NA
14	1.0040	0.075	0.30	2950	PM	NA
15	1.0000	0.075	0.30	2775	NN, WS	NA
16	1.0030	0.075	0.30	2740	NN, WS	NA
17	1.0030	0.075	0.30	2800	NN, WS	NA
18	1.0020	0.075	0.30	2850	NN, WS	NA
19	1.0030	0.075	0.30	2920	N	7/32 × 5/32
20	1.0010	0.075	0.30	2870	NN, WS	NA
21	1.0020	0.075	0.30	2875	NN, WS	NA
22	1.0000	0.075	0.30	2850	MT	NA
23	1.0010	0.075	0.30	2675	NN, WS	NA
24	1.0010	0.075	0.30	Metallographic Examination		
Average	—	—	—	2897	—	—
Std. Dev.	—	—	—	96	—	—

Notes: PM = The failure occurred within the parent material, far from the weld (not in the heat-affected zone).
NN = No nugget was formed as a result of testing.
WS = The weld sheared as a result of testing.
N = Nugget of weld was pulled out of specimen as a result of testing.
MT = Parent metal tore around the weld.
NA = Not applicable.

8.4 Spot Weld Peel Testing

Table 14 lists the test data acquired from peel testing the spot weld specimens. The specimens averaged a maximum peel load of 1010 lb, with a standard deviation of 108 lb. In each instance, the samples failed such that the metal tore around the weld region (the heat-affected zone), creating an immeasurable nugget, as shown in Figure 37. The torn metal contained the weld and thereby exceeded the 0.29-inch minimum nugget diameter required.

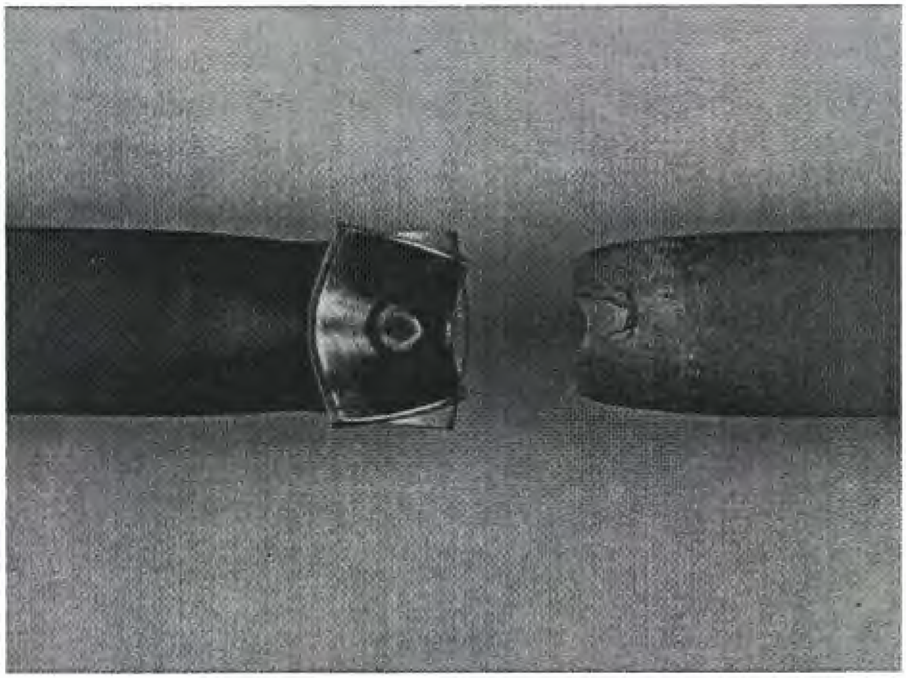

Figure 33. "Parent metal" failure of an improved spot weld tensile shear specimen; magnified 1×.

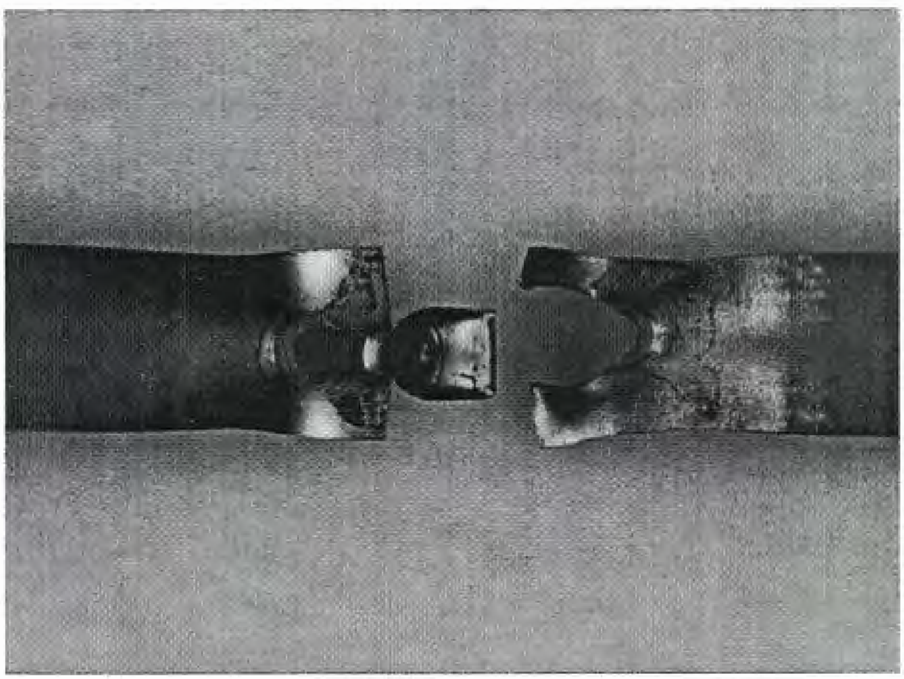

Figure 34. "Metal tearing" failure of an improved spot weld tensile shear specimen; magnified 1×.

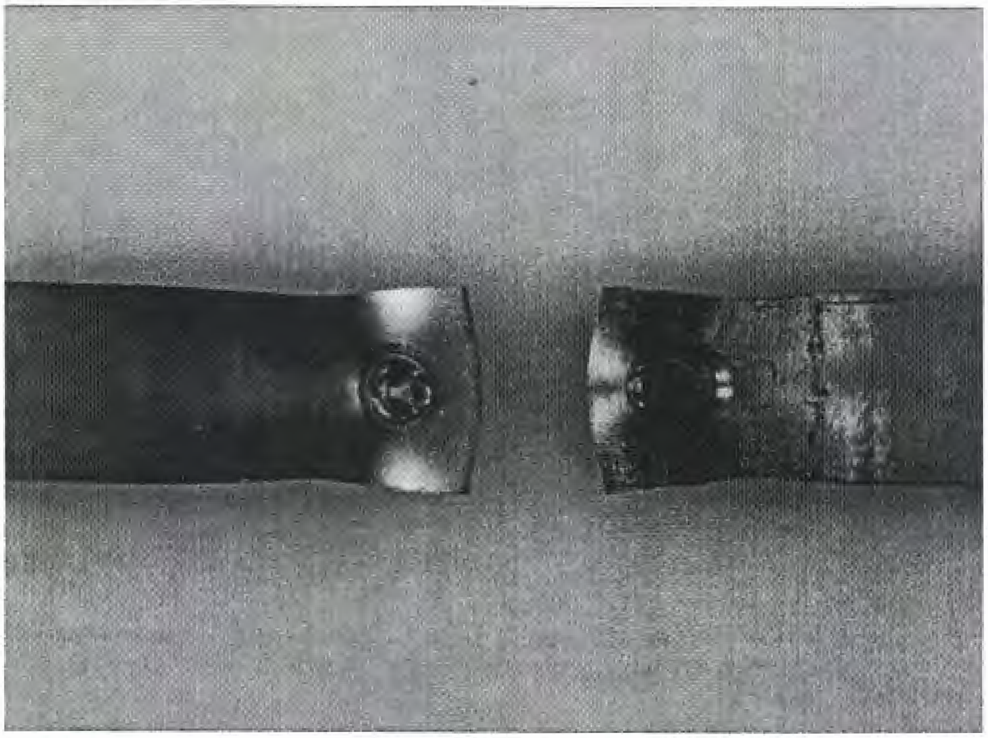

Figure 35. "Nugget formation" failure of an improved spot weld tensile shear specimen; magnified 1×.

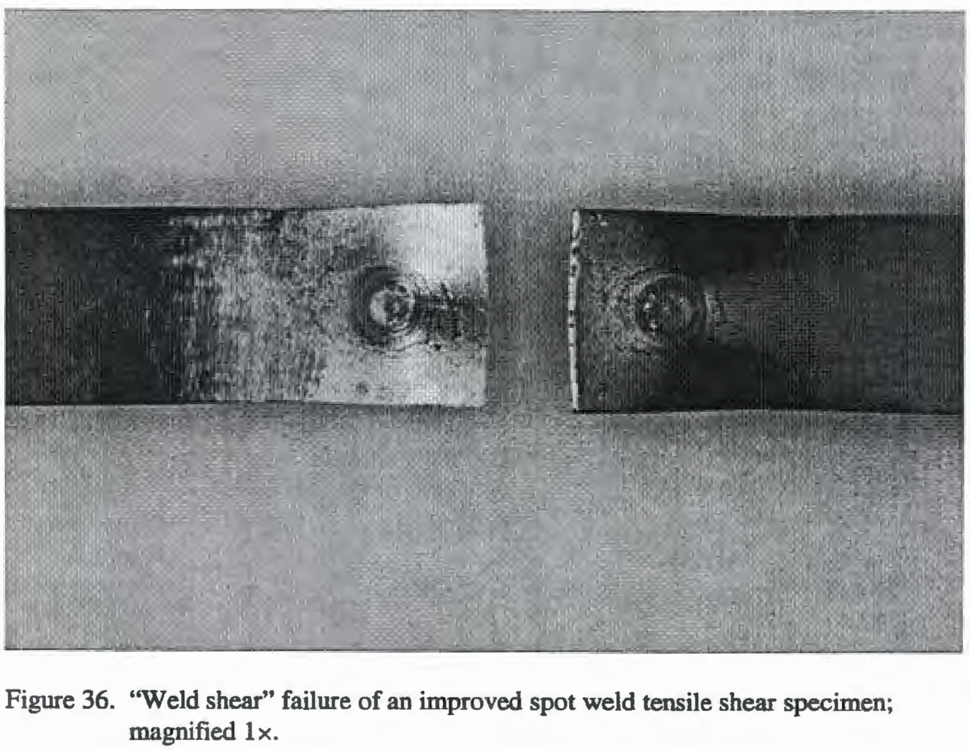

Figure 36. "Weld shear" failure of an improved spot weld tensile shear specimen; magnified 1×.

Table 14. Results of spot weld peel testing.

ID	Width (in)	Thickness (in)	Diameter of Weld (in)	Maximum Load (lb)	Break Comments	Nugget Diameter (Measured on Hole)
1	1.0005	0.075	0.30	1300	MT, NI	NA
2	1.0005	0.075	0.30	1025	MT, NI	NA
3	1.0040	0.075	0.30	890	MT, NI	NA
4	1.0005	0.075	0.30	940	MT, NI	NA
5	1.0030	0.075	0.30	1030	MT, NI	NA
6	1.0030	0.075	0.30	1040	MT, NI	NA
7	1.0015	0.075	0.30	1120	MT, NI	NA
8	1.0010	0.075	0.30	960	MT, NI	NA
9	1.0030	0.075	0.30	920	MT, NI	NA
10	1.0015	0.075	0.30	850	MT, NI	NA
11	1.0020	0.075	0.30	910	MT, NI	NA
12	1.0030	0.075	0.30	1140	MT, NI	NA
13	1.0025	0.075	0.30	780	MT, NI	NA
14	1.0010	0.075	0.30	1030	MT, NI	NA
15	1.0020	0.075	0.30	990	MT, NI	NA
16	1.0020	0.075	0.30	995	MT, NI	NA
17	1.0010	0.075	0.30	1040	MT, NI	NA
18	1.0000	0.075	0.30	1050	MT, NI	NA
19	1.0010	0.075	0.30	1060	MT, NI	NA
20	1.0010	0.075	0.30	1140	MT, NI	NA
21	0.9950	0.075	0.30	1040	MT, NI	NA
22	1.0010	0.075	0.30	980	MT, NI	NA
23	1.0010	0.075	0.30	1000	MT, NI	NA
24	1.0010	0.075	0.30	Metallographic Examination		
Average	—	—	—	1010	—	—
Std. Dev.	—	—	—	108	—	—

Notes: MT = Parent metal tore around the weld.
NI = Nugget was immeasurable.
NA = Not applicable.

9. Discussion

9.1 Quality of Welds

This investigation demonstrated that even in a nonproduction setting, the quality of the plug and spot welds was not easily assured. Once Aerotek enhanced their welding procedure, these welds showed improvement; however, the spot welds could have been optimized further. In any case, it was shown that even for these simple welds, care must be taken to create a quality weld. Despite this fact, it is believed that the criteria listed in section 10 are adequate in assuring a quality weld during production of the bomb fins. It should also be noted that bomb fin contractors would most likely extend considerable time and effort in optimizing these welds. For this investigation, only two trials were needed to produce specimens with high-quality welds.

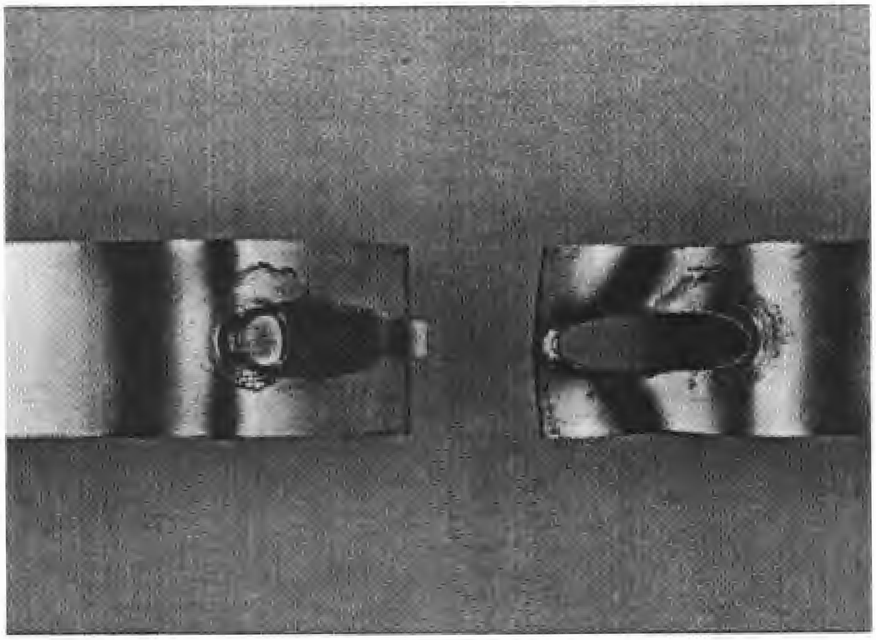

Figure 37. Typical failure of a spot weld peel specimen welded under improved conditions. Failure occurred by metal tearing initiated within the heat-affected zone; magnified 1×.

9.2 Inspection of Welds

Visual inspection is a suitable means of verifying the integrity of noncritical welds. However, care should be taken when assessing weld quality from solely visual inspection since it cannot be used to judge subsurface weld integrity. This is the reason that NDI often accompanies visual inspection requirements. Each of the welds discussed herein require visual inspection as part of the specification requirements. This method of inspection is used either with or without further NDI. Visual inspection is useful in checking for the following [13]:

- Dimensional accuracy of weldments,
- Conformity of welds to size and contour requirements,
- Acceptability of weld appearance with regard to surface roughness, weld spatter, and cleanliness, and
- Presence of surface flaws such as unfilled craters, pockmarks, undercuts, overlaps and cracks.

As stated in reference [13], NDI of weldments has two main functions:

(1) Quality control – the monitoring of the welder and equipment performance and of the quality of the consumables and the base materials used.

(2) Acceptance or rejection of a weld on the basis of its fitness-for-purpose under the service conditions imposed on the structure.

NDI is used primarily to inspect for surface or subsurface discontinuities. Methods generally used include liquid penetrant, magnetic particle, radiographic, ultrasonic, eddy current, and acoustic emission. The bomb fin governing specifications list NDI as required for both the plug (liquid penetrant or magnetic particle) and fillet (liquid penetrant or magnetic particle plus radiography) welds.

9.3 Mechanical Testing of Welds

The problem of predicting the performance of structures from a "laboratory-type" test is a complex one because the size, configuration, environment, and the type of loading normally differ [14]. No amount of mechanical testing will provide information regarding the suitability of the welded joints for service. However, in this investigation, ARL attempted to have specimens created in a production setting to (a) furnish welds whose mechanical properties would simulate those obtained by a bomb fin manufacturer and (b) establish a minimum criteria for samples made from actual bomb fins by a contractor.

9.4 Strength of Base Metal

The strength of resistance welds depends on the strength of the base metal, which in turn, depends on the composition, heat treatment, and degree of cold work [12]. As mentioned previously, AISI 1010 steel is utilized for the skins of both conical bomb fin designs. The sheets are required to be 0.075 ± 0.007-inch-thick (hot-rolled drawing quality). The ultimate tensile strength (UTS) of this material is 46,000 psi [15]. This is a typical value and could range, conservatively, ±5%. This would lead to a UTS range of 43,700–48,300 for this material. For a 1-inch section of both the seam and fillet weld, this specimen may have a thickness range from 0.068 to 0.082 inch, based on the dimensional tolerance of the material. The corresponding maximum attainable loads for these cross-sectional areas are 2971–3284 lb for the low-end UTS and 3583–3961 lb for the high-end UTS. Therefore, based on the dimensional tolerance and the mechanical property variability of the steel sheet, the material itself can exhibit a range of pull loads from 2971 to 3961 lb for a 1-inch wide specimen. These figures were taken into account when deriving the minimum load achievable for these types of weld specimens.

10. Recommended Testing and Inspection Criteria

The spot and seam welds examined in this study are classified as noncritical according to the governing drawings and specifications. The noncritical classification indicates that NDI (i.e., magnetic particle, liquid penetrant, or radiographic inspection) of these welds is not required. Although the seam weld lists MIL-STD-2219 as the alternative, MIL-W-12332 is the default specification and does not require NDI. The plug weld is governed by MIL-STD-2219, Class B. The Class B classification requires penetrant testing or magnetic particle inspection. The fillet weld is considered critical by the Class A designation of MIL-STD-2219. This specification states that Class A welds are critical where a failure of any portion would cause loss of the system, loss of major component, loss of control, unintentional release of critical stores, or endangering of personnel [3]. These welds are required to be radiographically inspected as well as either magnetic particle or penetrant inspected.

The destructive testing plan proposed by ARL would entail either a First Article sampling and/or a sampling of not more than 5% of a production run. The spot, seam, and fillet welds shall be sectioned from actual components and be visually inspected, mechanically tested, and metallographically inspected (if welds fail to meet the minimum mechanical properties). The plug weld specimens shall be fabricated as highlighted in section H.1 of Appendix H. The general criteria of the visual and metallographic inspections are described next.

10.1 Visual Inspection

In general, the workmanship of the welds shall be of a quality such that the outer surface of all welds shall be smooth and free of cracks, tip pickups, pits, metal expulsion, and other defects which would indicate the welds were fabricated with contaminated electrodes or with improperly prepared surfaces. Where practicable, all welds should meet with the adjacent metal in gradual, smooth curves. Fillet weld beads should be smooth and free of slag, excessive undercut, or excessive splatter. In no case should the weld metal be burnt (oxidized) or contain holes or pores through the material. The requirements listed in Table 2 shall apply.

10.2 Metallographic Inspection

Metallographic inspection is already required for the spot and seam welds, as dictated by MIL-W-12332. For the plug and fillet welds, ARL recommends that metallographic inspection should be necessary only as a result of weld specimens not meeting the minimum mechanical properties. In this manner, the possible reason for nonconformance may be established. However, metallographic inspection must be performed on specimens from the same production run as those that failed to meet mechanical properties. In general, the following characteristics should be examined when performing a metallographic inspection: weld fusion (including root and joint penetration—30%–80% for plug and spot welds), convexity, concavity, size of the bead, undercutting, overlapping, cracks, porosity, inclusions, and any other metallic discontinuities. Typically, minor defects toward the center of the weld are not of great concern. These generally do not play a role in either the performance of the weld or the mode of failure. However, when internal defects extend toward the weld edges, these can act as fast fracture paths upon loading. These types of defects are indicative of poor welds.

10.3 Establishment of Minimum Mechanical Property Criteria

Appendix H contains the proposed method of sectioning and testing welds for the MK83 and MK 84 conical bomb fins. As mentioned before, unlike the plug weld, the spot, seam, and fillet weld specimens can be sectioned directly from the bomb fins. In order to mechanically test the plug welds produced by a prospective manufacturer of these bomb fins, specimens would need to be generated similarly to those fabricated for this investigation.

10.3.1 Plug Weld

Based upon the results of the testing described herein, it is recommended that plug weld specimens fabricated by a bomb fin manufacturer having a 0.25-inch diameter shall achieve a minimum load of 2800 lb when subjected to a tensile shear test and a 700-lb load as a minimum when a single plug weld is subjected to a peel test. The general principles of ASTM A370 [16] shall be followed when performing these tests.

10.3.2 Spot Weld

It is recommended that spot weld specimens sectioned directly from a finished conical bomb fin having a 0.300-inch diameter shall achieve a minimum load of 2800 lb when subjected to a tensile shear test and a 1000-lb load as a minimum when a single spot weld is subjected to a peel test. The general principles of ASTM A370 shall be followed when performing these tests.

10.3.3 Seam Weld

The seam weld specimens averaged 3270 lb at a thickness of 0.073 inch. However, as mentioned previously, a sheet thickness as low as 0.068 inch could have been employed. At this thickness, an average load of approximately 3050 lb could be expected. Accounting for mechanical property variability, the maximum attainable load could be further decreased. Therefore, it is recommended that seam weld specimens sectioned directly from a finished conical bomb fin shall attain a minimum load of 2900 lb/linear inch of weld when tested in tension. The general principles of ASTM A370 shall be followed when performing these tests.

10.3.4 Fillet Weld

The fillet weld specimens averaged 3290 lb at a 0.073-inch thickness. If a sheet thickness as low as 0.068 inch was used, this load could have decreased to approximately 3060 lb. Again, taking into account mechanical property variability, it is recommended that fillet weld specimens sectioned directly from a finished conical bomb fin shall attain a minimum load of 2900 lb/linear inch of weld when tested in tension. The general principles of ASTM A370 shall be followed when performing these tests.

Table 15 outlines the summary of testing and inspection criteria recommended by ARL. NAWC may include these criteria in the appropriate ADLs or drawing packages to be referenced at their discretion during FAI and/or production of the MK83 and MK84 conical bomb fins. Welds meeting these criteria are assured of being high quality and will contribute to the overall integrity of the bomb fins.

Table 15. Summary of recommended test and inspection criteria.

Weld	Visual Inspection	Nondestructive Inspection	Mechanical Test	Minimum Test Load (lb)	Metallographic Inspection
Plug (0.25-inch diameter)	Yes	MPI (ASTM E1444) or liquid penetrant (ASTM E1417)	Tensile shear peel	2800 700	[a] [a]
Spot (0.30-inch diameter)	Yes	None	Tensile shear peel	2800 1000	See Table 6
Seam	Yes	None	Tensile shear	2900/linear inch	See Table 6
Fillet	Yes	MPI (ASTM E1444) or liquid penetrant (ASTM E1417) and radiography (ASTM E1742)	Tension	2900/linear inch	[a]

[a]Metallographic examination shall be performed only if specimens fail to meet the mechanical properties.

11. References

1. Naval Air Systems Command (NAVAIRSYSCOM). Drawings 1380505, 1380529, 1380509, 1380534, 1350494, 1380537, 1380507, 1380533, 1380506, and 1380531. Patuxent River, MD.
2. U.S. Department of Defense. *Welding, Metal, Metal Arc and Gas, Steels, and Corrosion and Heat Resistant Alloys; Process For.* MIL-STD-8611, Washington, DC.
3. U.S. Department of Defense. *Fusion Welding for Aerospace Application.* MIL-STD-2219, Washington, DC, 30 December 1988.
4. U.S. Department of Defense. *Welding, Resistance, Spot, Seam and Projection; for Fabricating Assemblies of Low-Carbon Steel.* MIL-W-12332, Amendment 3, Washington, DC, 29 August 1994.
5. American Society for Testing and Materials. "Standard Practice for Magnetic Particle Examination." ASTM E1444, West Conshohocken, PA, 2001.
6. American Society for Testing and Materials. "Standard Practice for Liquid Penetrant Examination." ASTM E1417, West Conshohocken, PA, 1999.
7. American Society for Testing and Materials. "Standard Practice for Radiographic Examination." ASTM E1742, West Conshohocken, PA, 2000.
8. U.S. Department of Defense. *Electrodes—Welding, Bare, Solid; and Fluxes, Submerged Arc Welding, Carbon and Low Alloy Steels.* MIL-E-23765/4, Washington, DC, 15 September 1989.
9. U.S. Department of Defense. *Electrode, Welding, Carbon Steel and Alloy Steel Bare, Coiled.* MIL-E-18193, Washington, DC, 23 August 1985.
10. American Society for Testing and Materials. "Standard Methods of Preparation of Metallographic Specimens." ASTM E3, West Conshohocken, PA, 2001.
11. Connor, L. P. (ed.). *Welding Technology*. Vol. 1, 8th edition, American Welding Society, p. 371, 1987.
12. ASM International. *Metallurgy of Welding and Joining*. Lesson 11, p. 24, 1985.
13. ASM International. *Welding, Brazing and Soldering*. Vol. 6, 9th edition, pp. 846–847, 1984.
14. Connor, L. P. (ed.). *Welding Technology*, Vol. 1, 8th edition, American Welding Society, p. 386, 1987.

15. Belfour Stulen Inc. *Structural Alloys Handbook*, 1982 edition. Vol. 2, Mechanical Properties Data Center, Columbus, OH, June 1986.

16. American Society for Testing and Materials. "Standard Test Methods and Definitions for Mechanical Testing of Steel Products." ASTM A370, West Conshohocken, PA, 2002.

Appendix A. Parameters Utilized by Aerotek for Plug Weld Fabrication

AEROTEK WELDING CO.

Tungsten Inert Gas Welding of Precision Aircraft Components

51 Loomis Street, North Granby CT 06060 (203) 653-0120

FWP 500

Fusion Welding Procedure
Process "A"

Job No: 91348
Part No: 0001AA (Attachment #1)
Issue Date: 9/27/91
Revision: None

Welding Specs: MIL-W-8611A
Filler Material: MIL-E-23765B ER70S-2
Cleaning: Acetone Wipe
Preparation: Silicon-Carbide Polish
Type of Joint: .250 Plug weld

Pre Heat: 68°-72° F (Room Temp.
Post Heat: — None
Backing: — None
No Passes: 2
Power Source: #1 Lincoln Squarewave

Welding Technique: Forehand: ✓ Backhand: Other:

Operating Parameters

No. Passes	Amps	Volts	Travel	Wire Size	Tung. Size
2	93-100	11	2 minutes weld time per spot	.062	3/32

Type Cup	C.F.H. Torch Gas	C.F.H. Purge Gas
#7	-12-	-0-

Approved By: [illegible signature]
Date: 9/27/91

FM 902

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Appendix B. Parameters Utilized by Aerotek for Spot Weld Fabrication

CERTIFIE: WELD SCHEDULE

Weld Schedule#: 12332A WS1

"Pertron Control PWC-300 Computer Input Data

Function	Step#	Control Code	A Data ~ = cycles	B Data
FOOT SWITCH CONTROL	00	401	000	01
DESCEND 97% POWER	01	002	000	97
SQEEZE 90 ~	02	800	090	00
WELD 5~ 65% POWER	03	131	005	65
WAIT 2~	04	800	002	00
WELD 5~ 65% POWER	05	131	005	65
WAIT	06	800	060	00
END	07	003	000	00

Manufacturing Instruction Sheet

Welding Machine ID: SCIAKY

Electrode ID: TOP / BOTTOM 5327-128

Fixture ID: N/A

External water: X Yes ___ No

Minimum Spot Width: .300

Ram Pressure P.S.I.G. Down 24 Up 20

Max. Indentation %: 10%

Penetration Range %: 30% / 80% Minimum/Maximum

Weld Type: X Spot ___ Seam ___ Stitch ___ Projection

Required Weld Specs.: MIL-W-12332A

Weld Inspection Specs.: MIL-W-12332A

Min. Shear Tensile Strength: N/A

Remarks/Sketch:
MAT'L MUSH BE WIPE CLEAN
OVER LAP 1" 29 SPOT WELD
2 STRIPS 2'8"L 4"W

Seam Motor Speed: N/A

Stitch Weld Pitch: N/A

Prepared by: GARY LAKES

Approved by: ______ Quality Manager

Date: 2OCT91

WELD INSPECTION SCHEDULE FORM

RESISTANCE WELDING INSPECTION AND LABORATORY REPORT (USE BALL POINT PEN ONLY)

TEST	TEST		—	—	—	—	TEST	—	AISI 1010		.073	SEAM	☐
A2332A-WS1	SCIAKY	120 CLB	—	—	—	—	TEST	—	AISI 1010		.073	SPOT	☒
20CT91		—	—	—	—	—	—	—	—		—		
GARY LAKES			—	—	—	—	—	—	—		—	STITCH	☐

TIME/FREQUENCY STAMP

TEST NO.	DRAWING REQUIREMENTS							MICRO RESULTS				
	[illegible]	[illegible]	[illegible]	% [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
A	AISI 1010	.073		2%		1"	— .290		N/A		OK	[illegible]
A1	AISI 1010	.073		8%		1"	— .290		N/A		OK	[illegible]
A2	AISI 1010	.073		2%		1"	— .290		N/A		OK	[illegible]
A3	AISI 1010	.073		2%		1"	— .290		N/A		OK	[illegible]
A4	AISI 1010	.073		2%		1"	— .290		N/A		OK	[illegible]
A5	AISI 1010	.073		2%		1"	— .290		N/A		OK	[illegible]
M/S	/	/		/		—	—	/	—		—	—

REMARKS: ALL PEEL TEST PER A2332A -(IN COMPLIANCE)

X-RAY REQUIREMENTS	[illegible]	[illegible]	X-RAY RESULTS	DATE	INITIALS
N/A			N/A		

Appendix C. Parameters Utilized by Aerotek for Seam Weld Fabrication

CERTIFIED WELD SCHEDULE

Weld Schedule#: 12332A-WS1

Pertron Control PWC-300 Computer Input Data

Function	Step#	Control Code	A Data ~ = cycles	B Data
FOOT SWITCH CONTROL	00	401	000	01
DESCEND AT 97% POWER	01	002	000	97
SQUEEZE 30~	02	800	030~	00
WELD 5~ 50% POWER	03	131	005~	50
0~ WAIT TO REVERSE POLARITY	04	800	000~	00
WELD 5~ 50% POWER	05	131	005~	50
SQUEEZE 5~	06	800	005~	00
ROTATE SEAM WHEEL FOR 27~	07	303	027~	01
GO TO STEP 03	08	900	003~	02
SQUEEZE 60~	09	800	060~	00
END	10	003	000	00

Manufacturing Instruction Sheet

Welding Machine ID: SCIAKY
Required Weld Specs.: MIL-W-12332A

Electrode ID: 2 12" Ø CLASS 2 WHEELS
Weld Inspection Specs.: MIL-W-12332A

Fixture ID: NONE USED
Min. shear Tensile Strength: N/R

External water: X Yes ___ No
Remarks/Sketch:
MATERIAL MUST BE CLEAN
OVERLAP IS 1 INCH
10 WELDS/INCH

Minimum Spot Width: ~~.200~~ .250

Ram Pressure P.S.I.G. Down 24 Up 20

Max. Indentation %: 10%

Penetration Range %: 30 / 80 (Minimum/Maximum)

Weld Type: ___ Spot ✓ Seam ___ Stitch ___ Projection

Seam Motor Speed: 400

Stitch Weld Pitch: ___

Prepared by: [signature] Approved by: [signature] Quality Manager Date: 8/2/91

WELD INSPECTION SCHEDULE FORM

RESISTANCE WELDING INSPECTION AND LABORATORY REPORT (USE BALL POINT PEN ONLY)

TEST REF. NO.: TEST	[illegible]: TEST	[illegible]: —	[illegible]: —		[illegible]: —	[illegible]: TEST		[illegible]: K10		[illegible]: 02
123329-651	SCIAKY	LCE CC 2	—	—		—	TEST		KC10	.072
DATE: 10/30/91	[illegible]: —									

WELD TYPE: SEAM ☑ SPOT ☐ STITCH ☐

TIME FREQUENCY STAMP

DRAWING REQUIREMENTS

TEST NO.	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	MICRO RESULTS % PENETR.	MICRO RESULTS DEFECTS	[illegible]	[illegible]	INITIALS
A		.072		2%	10/20	1.001 / FLUSH	— / .290	65%	NONE		OK	[illegible]
A1		.072		2%	10/20	1.001 / FLUSH	— / .290	65%	NONE		OK	[illegible]
A2		.072		2%	10/31	1.001 / FLUSH	— / —	65%	NONE		OK	[illegible]
A3		.072		2%	10/31	1.001 / FLUSH	— / —	65%	NONE		OK	[illegible]
A4								*				
A5												
A6/B												

REMARKS: WELD CERTIFICATION

* MICRO ETCH DID NOT DEVELOPE WELL VISUAL ESTIMATE WITH DIAL CALIPERS PULL TEST - NOT ABLE TO SEPERATE BY HAMMER + PULLER

[illegible] REQUIREMENTS	[illegible]	[illegible] RESULTS	DATE	INITIALS
N/R		N/R		

Appendix D. Parameters Utilized by Aerotek for Fillet Weld Fabrication

AEROTEK WELDING CO.

Tungsten Inert Gas Welding of Precision Aircraft Components

51 Loomis Street, North Granby CT 06060 (203) 653-0120 FWP 500

Fusion Welding Procedure
Process "A"

Job No: 91248
Part No: 001AC
Attachment #3
Issue Date: 9/26/91
Revision: None

Welding Specs: Mil-W-8611A
Pre Heat: Room Temp 68°-70°F
Post Heat: None (Air Cool
Filler Material: Mil-E-23765B ER705-2
Backing: —
Cleaning: Acetone Wipe
No Passes: 1
Preparation: Silicon Carbide Polish
Power Source: #1 Lincoln Syncrowave
Type of Joint: .075 Deep Single "U" Groove

Welding Technique: Forehand: ✓ Backhand: Other:

Operating Parameters

No. Passes	Amps	Volts	Travel	Wire Size	Tung. Size
1	115-120	11	5 IPM	.062	3/32 2% Thor.

Type Cup	C.F.H. Torch Gas	C.F.H. Purge Gas
#7	-12-	-0-

Approved By: Robert W. Fusick
Date: 9/26/91

FM 902

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Appendix E. Chemical Analysis of the Weld Wire Used by Aerotek Welding

AEROTEK. WELDING
51 LOOMIS ST
NORTH GRANBY CT 06060

P/O V-808 P/S 72577

301 CLAY STREET
BOWLING GREEN, KENTUCKY 42101
Telephone 502 781-5560

CHEMICAL ANALYSIS REPORT

Date: 6/4/87

Shipped To: Zane Weld Craft
95 Maxim Road
Hartford, Ct. 06114

Customer's Order: Verbal/B.Clar

Zane Weldcraft Supplies

Via: Truck

Our Register:

Pallets: 1

Gross: 260

Net: 260

Material: 1/16 x 18 5# Tubes Heat #37401 Page AS35 Weld Test 487 Flag Tag 1 and AWS Specification A5.18/ER70S-2 ASME/SFA5.18 Classification ER70S-2 ASME Boiler and Pressure Vessel Code Section III MIL-E-23765/1-70S-2 Q.P.L. GL53-2 G.E. Specl B21B90B 260# 1/16 x 18

Heat No.	C	Mn	P	S	Si	Mo	Cu	Al	Ni	Ti	Zr
37401	.054	1.12	.011	.019	.49		.023	.09		.10	.069

We certify that these chemical test results are correct as contained in the records of the company.

J. T. Crane, Chief Chemist

Mechanical Properties as welded

Tensile PSI	Yeild	Percent Elongation
78.550.	64,500.	24.5%

Radiographic Test Passed April 23, 1987

Charpy Ft-lb-20°F	Mils lat Exp	Est % Shear
187.0	98.5	70
88.0 (not used)	7.05	40
146.0	87.0	40
128.5	83.0	45
239.5 (not used)	91.0	N/A
153.8 Average		

Gine 10-3-4 Nov 2005 Got 2005 2000

American Chain & Cable Company, Inc. A Member of the Babcock & Wilcox, Limited Group of Companies

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Appendix F. Parameters Utilized by Aerotek for Improved Plug Weld Fabrication

AEROTEK WELDING CO.

Tungsten Inert Gas Welding of Precision Aircraft Components

51 Loomis Street, North Granby CT 06060 (203) 653-0120 FWP 500

Fusion Welding Procedure
Process "A"

Job No: 92113
Part No: Plug Weld test Shear & Peel
Issue Date: 11/12/92
Revision: None

Welding Specs: Mil-W-8611A
Pre Heat: 68° - 72°F (Room Temp)
Post Heat: – None –
Filler Material: Mil-E-23765 B (ER70S-2)
Backing: – None –
Cleaning: Acetone Wipe
No Passes: 2
Preparation: Silicon Carbide Polish
Power Source: #1 Lincoln
Type of Joint: .250 Plug Weld for both test samples

(Fuse Root all around prior to Adding filler Material)

Welding Technique: Forehand: ✓ Backhand: Other:

Operating Parameters

No. Passes	Amps	Volts	Travel	Wire Size	Tung. Size
2	97-165	11	2 min. weld time per joint	.062	3/32

Type Cup	C.F.H. Torch Gas	C.F.H. Purge Gas
#7	-12-	-0-

Approved By: [signature]
Date: 11/12/92

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Appendix G. Parameters Utilized by Aerotek for Improved Spot Weld Fabrication

CERTIFIED WELD SCHEDULE

Weld Schedule#: MIL-W-12332A-WS 3

Pertron Control PWC-300 Computer Input Data

Function	Step#	Control Code	A Data ~ = cycles	B Data
FOOT SWITCH CONTROL	00	401	000	01
DESCEND 97% POWER	01	002	000	97
SQEEZE 90~	02	800	090	06
WELD 5~ 44% POWER	03	131	006	44
WAIT 1~	04	800	001	00
REPEAT	05	004	003	03
WAIT	06	800	040	00
END	07	003	000	00

Manufacturing Instruction Sheet

Welding Machine ID: SCIAKY — Required Weld Specs.: MIL-W-12332A

Electrode ID: Top WG250B - Bottom 5327-100 — Weld Inspection Specs.: MIL-W-12332A

Fixture ID: N/A — Min. shear Tensile Strength: N/A

External water: X Yes ___ No — Remarks/Sketch: MAT'L. MUST BE FREE OF OIL + DIRT BEFORE WELDING

Minimum Spot Width: .300

Ram Pressure P.S.I.G. Down 20 Up 20

Max. Indentation %: 10%

Penetration Range %: 20% / 80% (Minimum/Maximum)

Weld Type: X Spot ___ Seam — Seam Motor Speed: N/A

— Stitch — Projection — Stitch Weld Pitch: N/A

Prepared by: [signature] Approved by: [signature] Date: 1/28/92

WELD INSPECTION SCHEDULE FORM

RESISTANCE WELDING INSPECTION AND LABORATORY REPORT (USE BALL POINT PEN ONLY)

TEST	SPOT WELD TEST		—	—	—	—	TEST	—	AISI 1010		.073	SEAM ☐
	SCIAKY	120 CL2	—	—	—	—	TEST	—	AISI 1010		.073	SPOT ☒
29 Jan 92	—	—	—	—	—	—	—	—	—	—	—	STITCH ☐
			—	—	—	—	—	—	—	—	—	

TIME FREQUENCY STAMP

DRAWING REQUIREMENTS

Test No.												
A	AISI 1010	.073				1"	3000# / 330	60%	N/A	1	OK	[illegible]
A1	AISI 1010	.073				1"	3000# / 310	55%	N/A	1	OK	[illegible]
A2	AISI 1010	.073				1"	3000# / 342	55%	N/A	1	OK	
A3	AISI 1010	.073				—	— / 330	59%	N/A	1	OK	[illegible]
A4	ABI 1010	.073				—	— / 330	60%	N/A	1	OK	[illegible]
A5	AISI 1010	.073				—	— / 320	55%	N/A	1	OK	
	—	—				—	—	—	—	—	—	—

REMARKS: ALL SPOT WELD TEST SPECIMENS PER MIL-W-12332 A

X-RAY REQUIREMENTS

N/A

X-RAY RESULTS

N/A

Appendix H. Proposed Method of Sectioning and Testing Welds for the MK83 and MK84 Conical Bomb Fins

H.1 Plug Weld Test Specimens

As previously stated, plug weld test specimens cannot be sectioned directly from the conical bomb fins due to their geometry. Therefore, it is necessary for the contractor to fabricate specimens in a production run-like manner, similar to the method in which Aerotek employed. The plug weld assembly is shown in Figure H-1. This method is described as follows:

> The contractor shall fabricate 24 plug weld specimens upon two (2) 4- × 24-inch AISI 1010 steel (hot-rolled drawing quality) sheets. The thickness of the sheets shall be 0.075 inch ± 0.007 inch. The centers of each plug weld shall be spaced at 1-inch intervals. The two sheets of steel shall overlap by 1 inch in the center. The diameter of the holes drilled into one of the sheets (to be filled by the plug weld) shall be 0.25 inch. The welds shall be in accordance with the requirements of MIL-STD-2219,[1] Class B. The electrodes shall be in accordance with MIL-E-23765/1,[2] Type 70S-2 or 70S-3. The welded sheets shall be sectioned without burning into 1.000-inch +0.005-inch/–0.000-inch strips, with the plug weld centered in each strip. The strips shall be labeled in order of construction, 1 to 24. The following schematic illustrates the specimen dimensions.

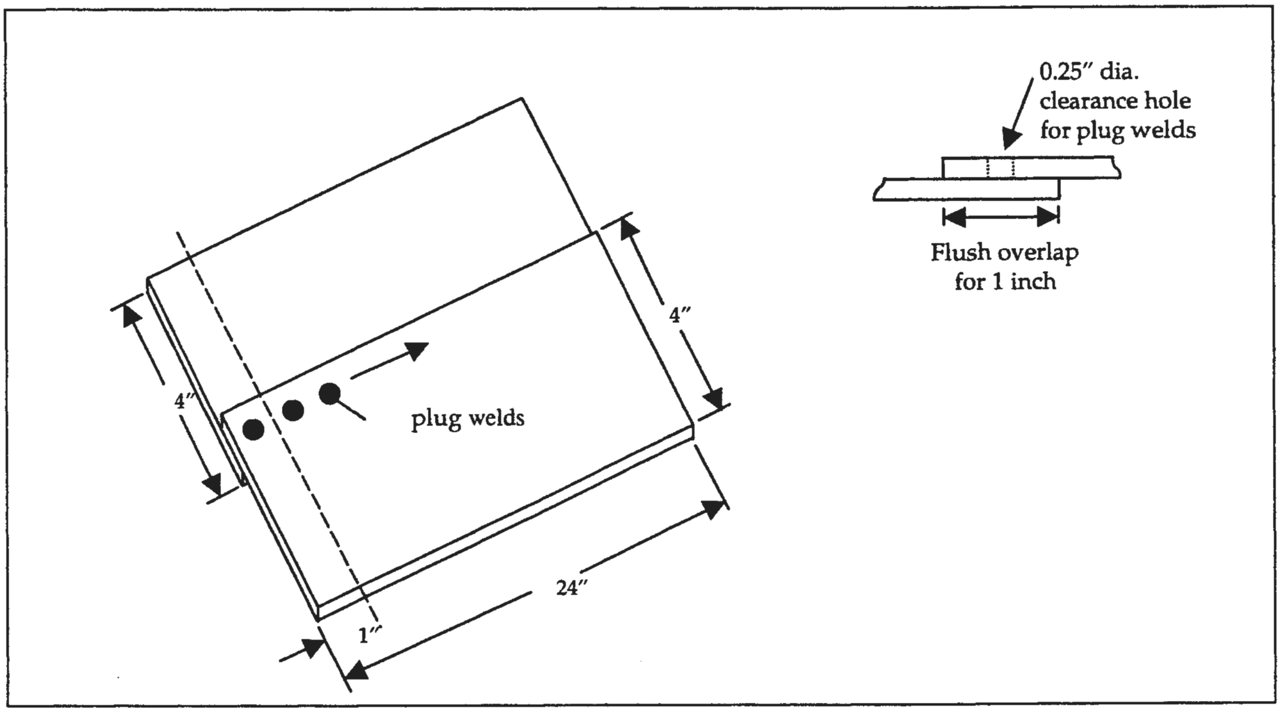

Figure H-1. Plug weld assembly.

[1] U.S. Department of Defense. *Fusion Welding for Aerospace Application.* MIL-STD-2219, Washington, DC, 30 December 1988.

[2] U.S. Department of Defense. *Electrodes—Welding, Bare, Solid; and Fluxes, Submerged Arc Welding, Carbon and Low Alloy Steels.* MIL-E-23765/4, Washington, DC, 15 September 1989.

H.2 Spot Weld Test Specimens

Spot weld tensile shear and peel specimens may be sectioned directly from a conical fin spar prior to assembly of the conical bomb fin. The method of sectioning is illustrated schematically in Figure H-2. One conical fin yields two spot weld peel and one spot weld tensile shear specimens. Strips should be sectioned to 1-inch widths.

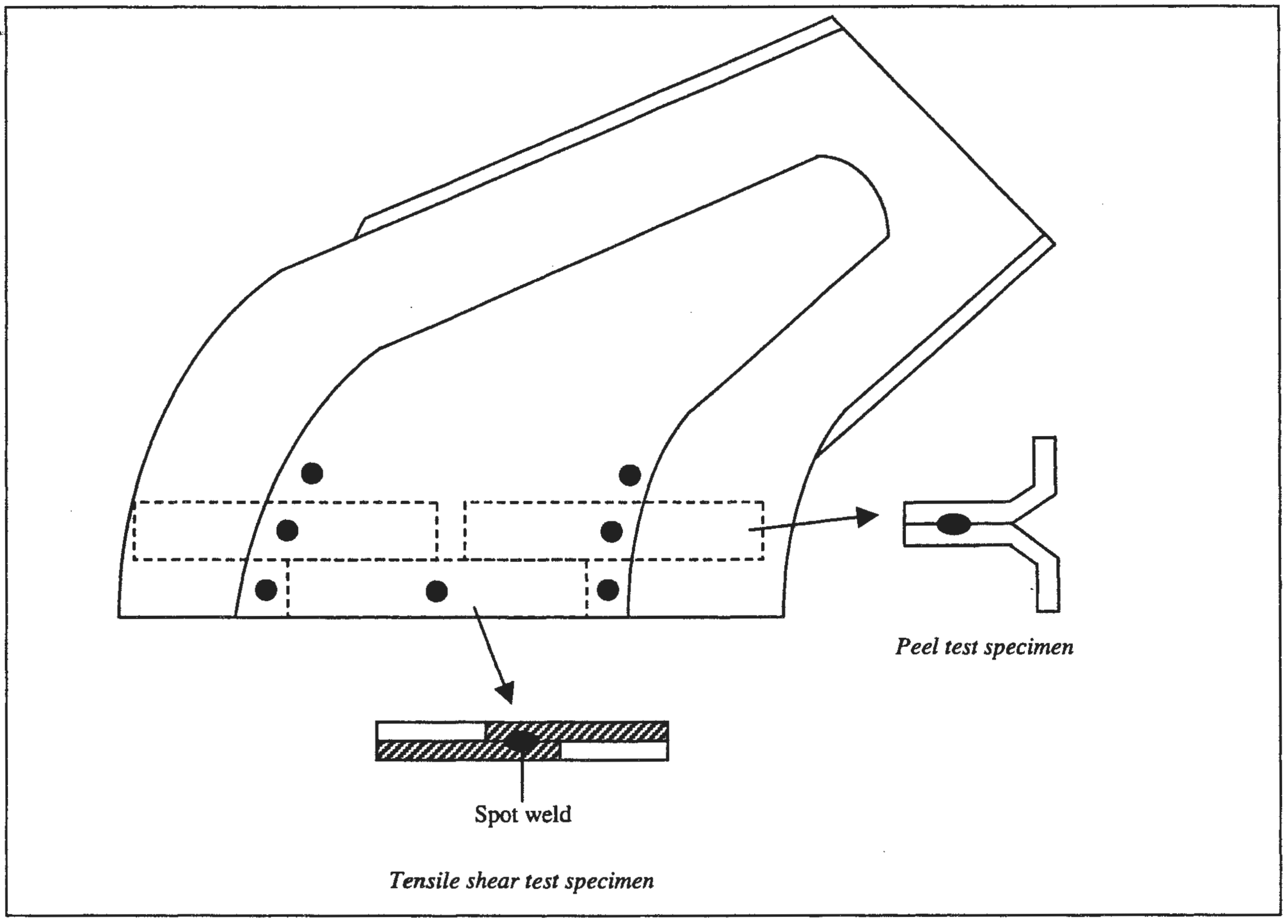

Figure H-2. Method of sectioning for spot weld specimens.

H.3 Seam Weld Test Specimens

Seam weld shear specimens may be sectioned directly from a completed conical bomb fin, provided the specimens are sectioned as close to the ring support as physically possible. This minimizes specimen curvature and allows for an axial shear test. Another restriction is that only a maximum of three specimens may be sectioned from a single bomb fin because of the increased skin curvature as the end of the fin is approached. The method of sectioning and the special test fixture needed are illustrated in the schematics of Figures H-3 through H-5.

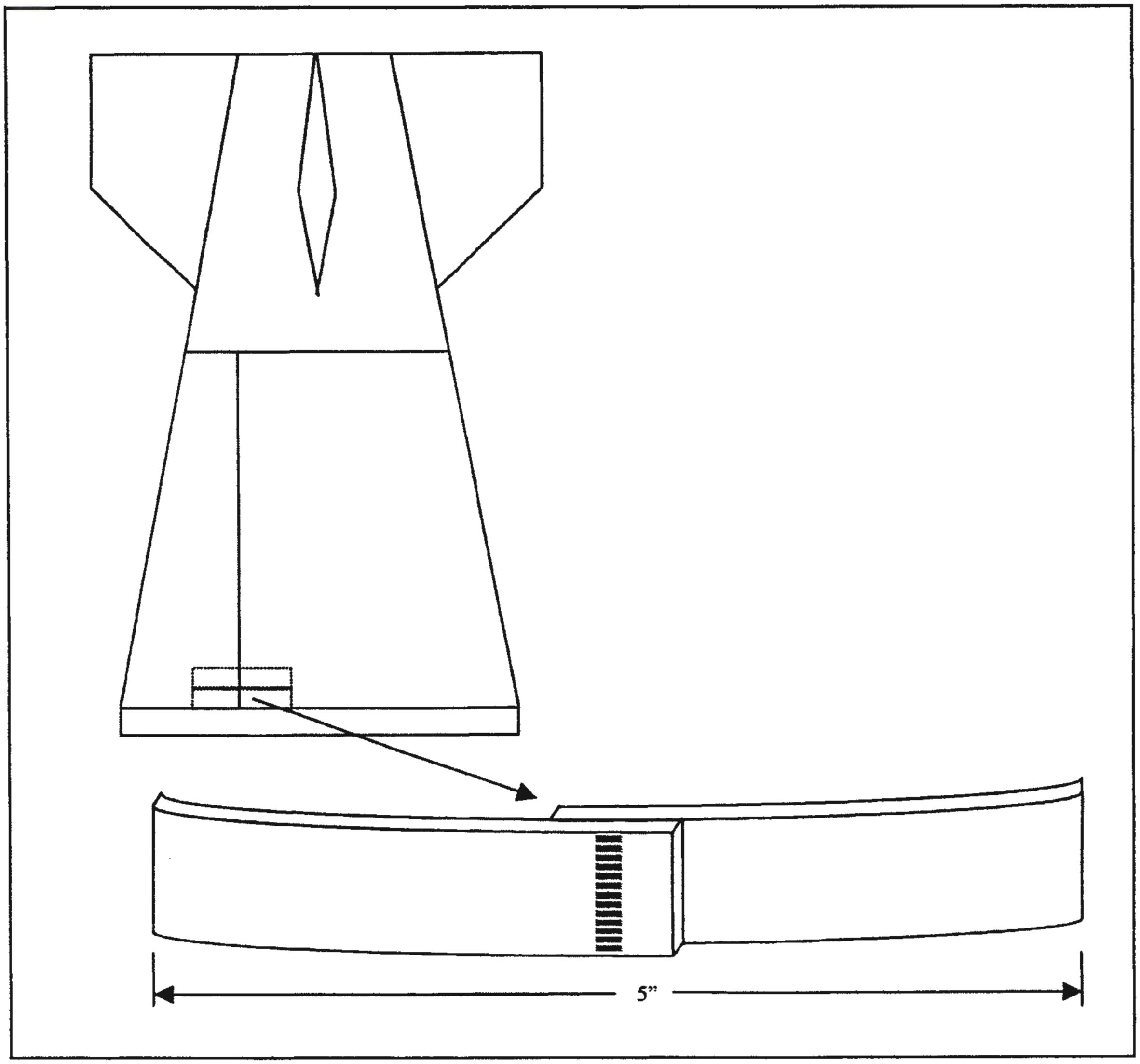

Figure H-3. Method of sectioning for seam weld specimens.

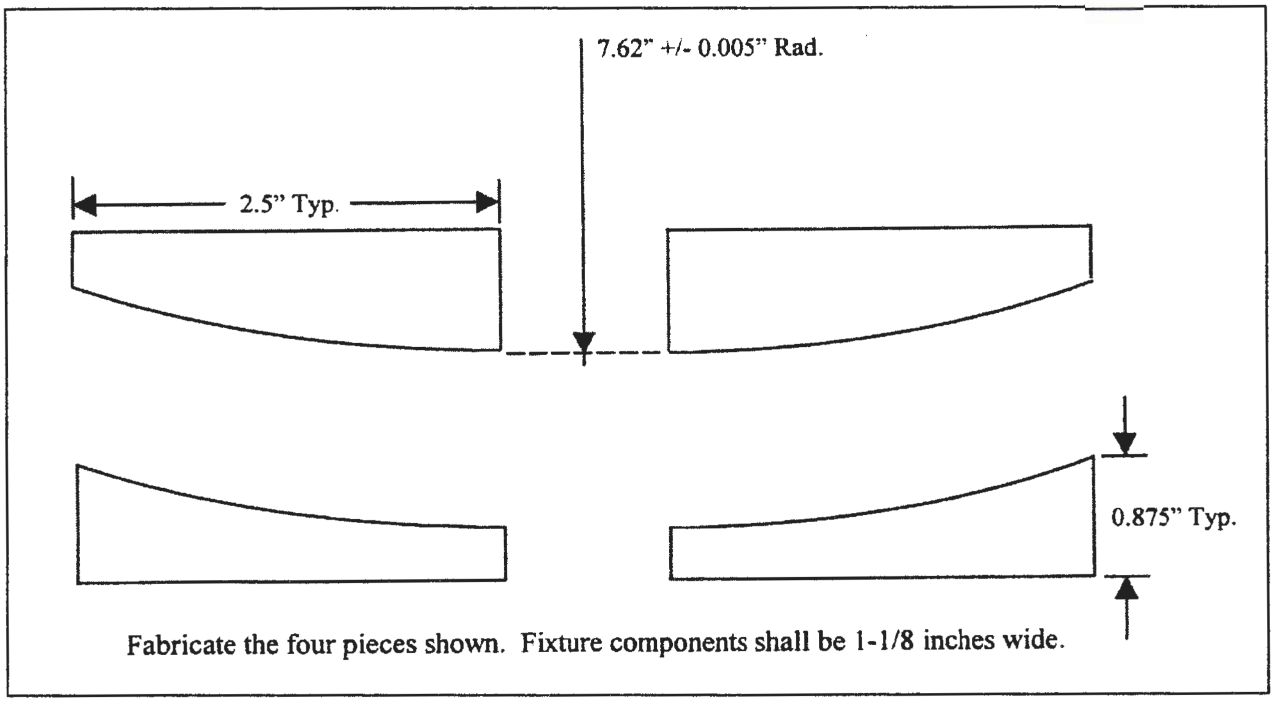

Figure H-4. Seam weld fixture dimensions (material shall be AISI 4XXX steel, HRC 35–40).

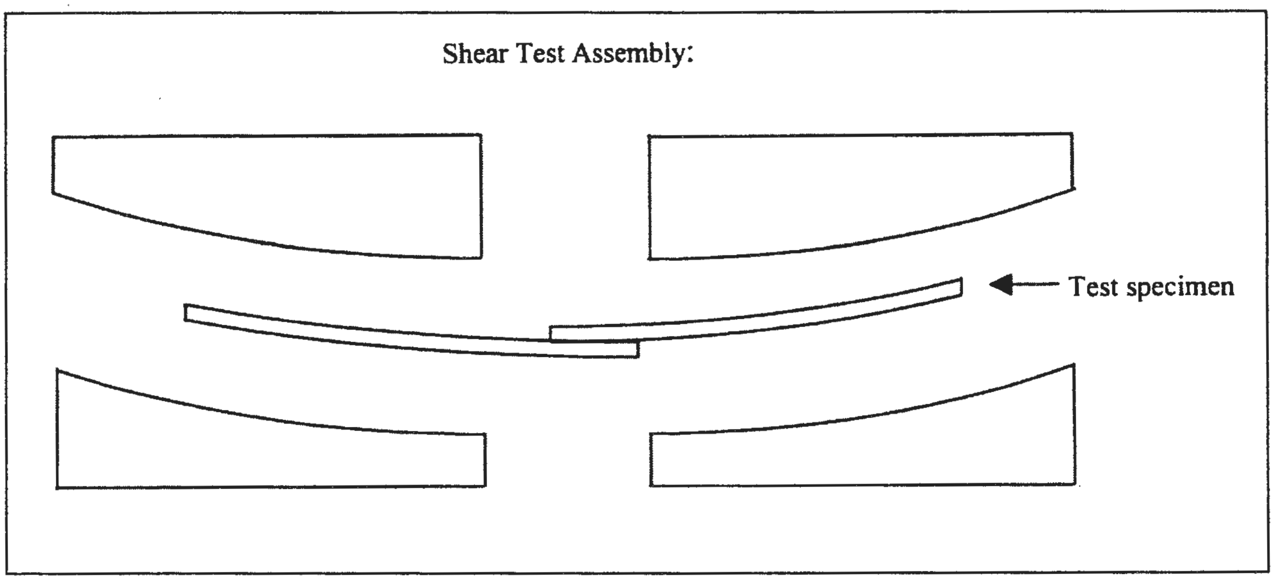

Figure H-5. Shear test assembly for seam weld specimens.

H.4 Fillet Weld Test Specimens

Fillet weld pull test specimens may be sectioned from a completed bomb fin, provided each specimen is 1-inch in diameter. This minimizes specimen curvature, which improves the gripping ability of the specimens during testing. The method of sectioning and the special fixture necessary for testing are illustrated in the schematics of Figures H-6 through H-8. One bomb fin yields over 30 fillet weld pull test specimens.

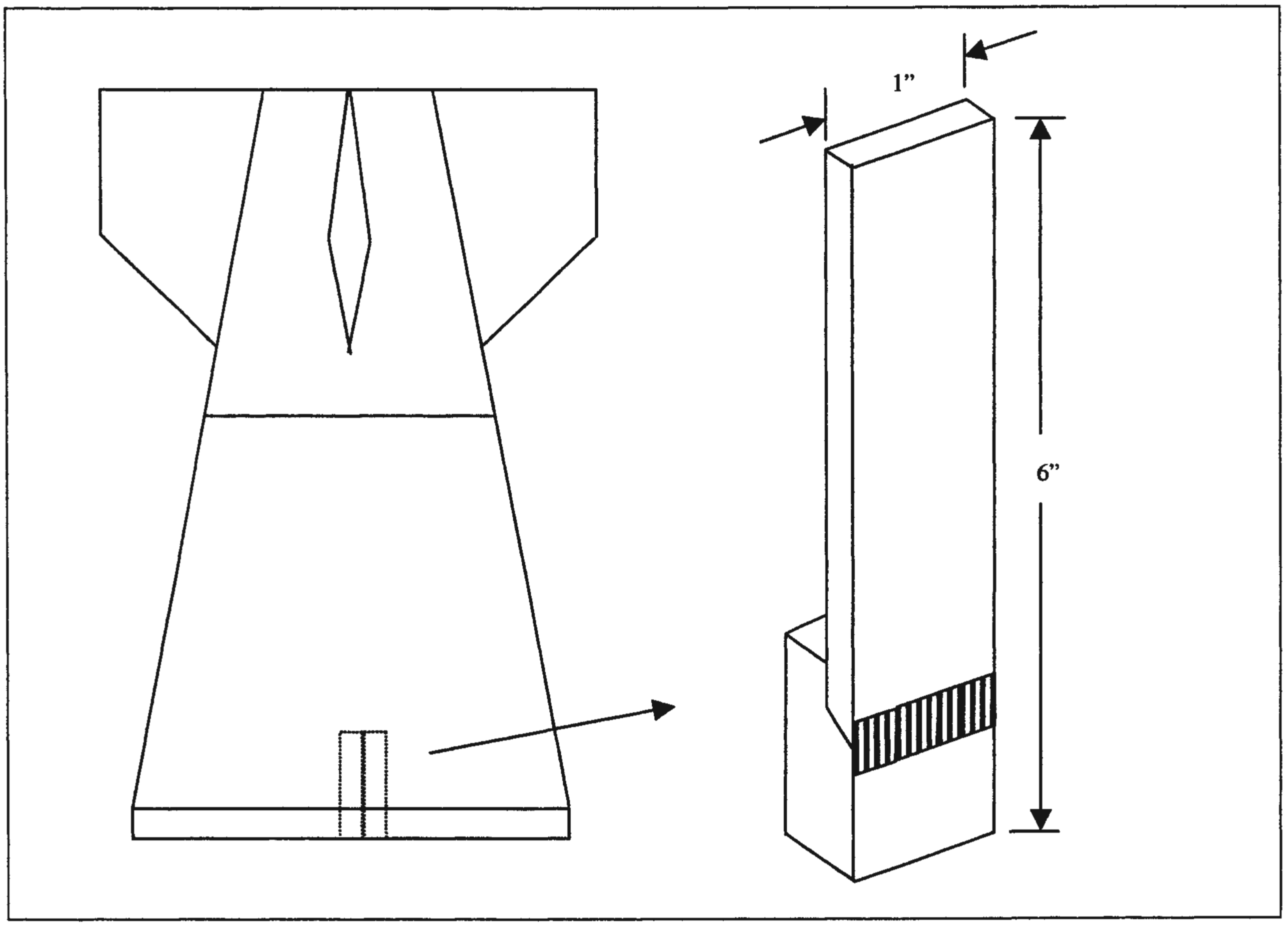

Figure H-6. Method of sectioning for fillet weld specimens.

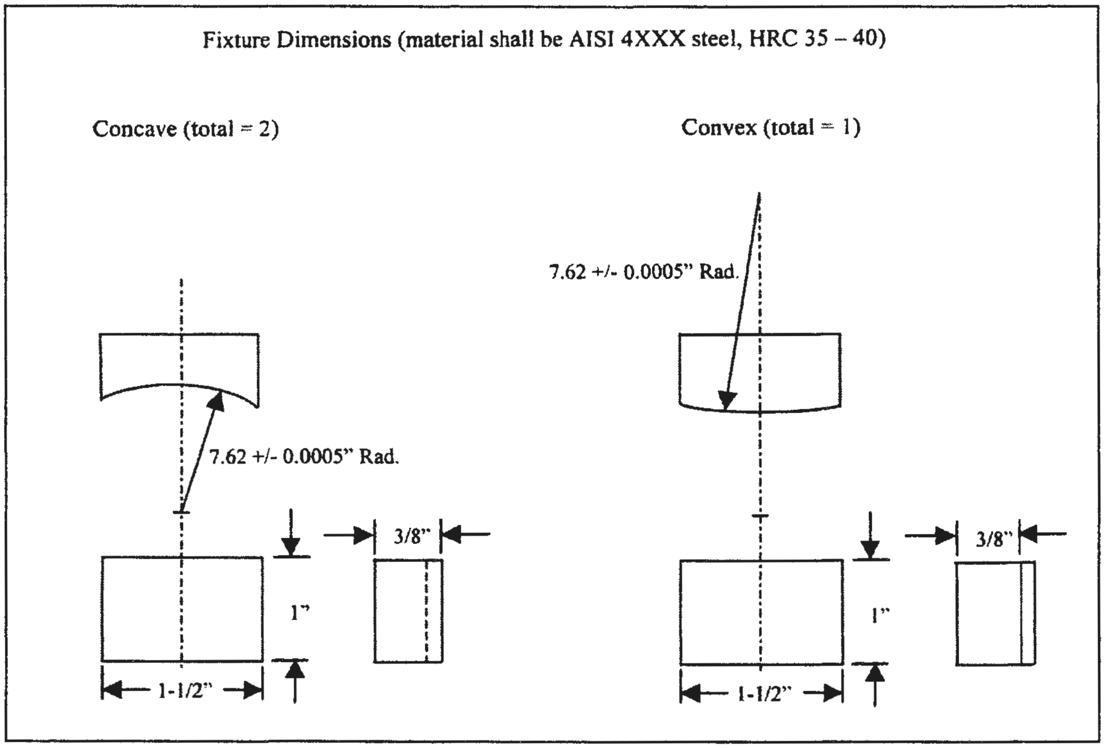

Figure H-7. Fillet weld fixture dimensions (material shall be AISI 4XXX steel, HRC 35–40).

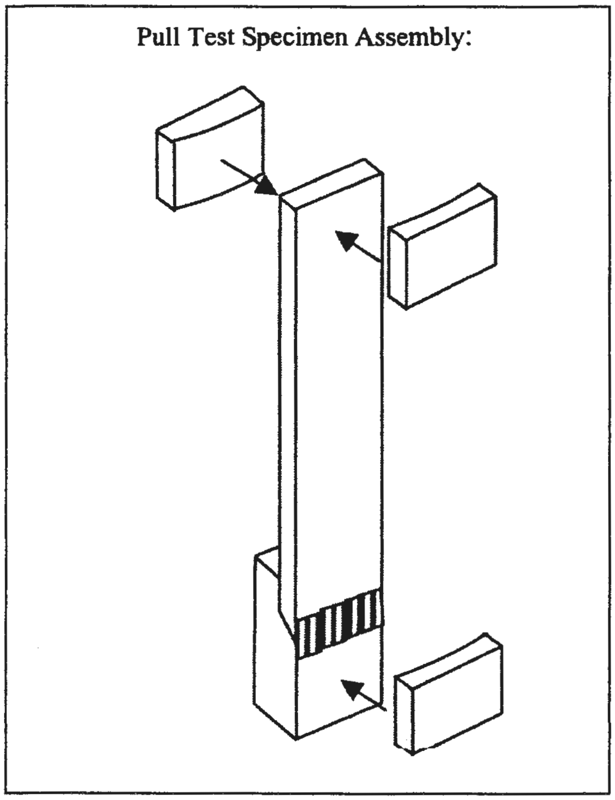

Figure H-8. Pull test assembly for fillet specimen.

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13. ABSTRACT*(Maximum 200 words)*

The U.S. Army Research Laboratory (ARL) performed weld strength verification testing on manufactured specimens to characterize four different types of welds found on both the MK83 and MK84 conical bomb fins. Based on the results obtained by testing, as well as existing requirements, ARL established test and inspection criteria that may be employed at the discretion of the Naval Air Warfare Center for future First Article Inspections and/or during production as a tool for evaluating the quality and integrity of the weldments.

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